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SEE Sight Effectiveness Enhancement Results of the Automotive Evaluation

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October 2006

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Abstract (max. 2000 char.):
In the SEE project two parallel evaluations have been conducted, an experimental trial of the automotive and another of the aeronautical application. The evaluations have measured the efficiency and HMI (human-machine interaction) characteristics of the SEE prototype. This report covers the automotive part of the evaluation.
The evaluation of the automotive application was carried out in computer simulated environments and followed the general objectives of the evaluation described in 'Definition of the Evaluation Plan'[1]. The field experiment discussed, however, was given up due to lack of control of the experimental variables, especially the variability of foggy conditions.
The simulation-based experiment reported here was conducted as a repeated measures design involving 20 subjects, all experienced in driving in all kinds of weather. The objective of the evaluation was to assess the possible advantage of having the SEE system available in three weather conditions: day with fog, night in clear weather and night with fog. Assessment was based on subjects' detecting, recognising and reacting to hazardous situations in traffic in a simulated ride. Two measures were used:
Objective measure: a comparison of reaction times for identical scenarios, but under different weather conditions.
Subjective measure: a questionnaire assessing the subjects' opinions regarding the perceived enhancement of visibility gained by the infrared images compared to normal conditions (not having the infrared images available).
Results of the evaluation showed a comprehensive improvement for night vision in clear weather, whereas no enhancement was demonstrated during foggy conditions. In this report, we discuss and document the fact that the results of the experimental evaluation clash with the experience gained when assessing the SEE prototype during test rides carried out in Germany during foggy conditions. The reasons for the difference in performance of the real SEE system and the simulated system appear to do with the parameterization of the simulated fog, which is described briefly in the main text of this report and in detail in Appendix 8.
Results of the subjective measures, the questionnaire data, reveal positive attitudes toward the SEE system.

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1 SEE deliverable D6.1, Definition of the Evaluation Plan

Contents

1 Objective of the automotive evaluation 4

2 Experimental considerations 4

3 Test protocol 6

3.1 Briefing 6
Confidentiality 6
Background information 6
Visual acuity and contrast sensitivity test 7
Technology 7
Instruction 9
3.2 Test session 9
3.3 Debriefing 10

4 Evaluation of SEE enhanced vision system 10

4.1 Experimental design 10
4.2 Subjects 11
4.3 Results of the time of reaction test 13
4.4 Results of the questionnaire 16
4.5 General comments from the sessions 21

5 Discussion 22

5.1 Advantage of Prototype system contradicting the simulated system in foggy conditions 22
5.2 Parameter selection 25

6 Conclusion 27

7 Annexes 29

1 Objective of the automotive evaluation

The task covered in this report is the automotive evaluation, in which the enhanced vision system, SEE, has been tested in virtual environments based on simulations of a test-driving in a car under various weather conditions, such as daylight in foggy weather, and night in clear weather and foggy weather, respectively. Daylight in clear weather has not been tested due to the fact that the SEE system is not expected to be used in this type of weather, in which full visibility is on hand.

The simulations have been based on a real driving exercise in fine weather with a normal video camera mounted on a car. Based on this video, the same trip has been simulated for normal vision as corresponding to driving without having available a sight enhancement system, and for presentations using infrared cameras for two types of different wavelengths of infrared, a long wave infrared, LWIR from 8 to 14 µm, and a short wave infrared, SWIR from 1 to 2.5 µm. These presentations are used as basis for the enhanced vision. For all situations various weather conditions have been added. In order to benefit from the advantage of both types of infrared bands, the two types are combined in a single fused presentation.

For the test sessions the two types of presentation, the normal vision and the infrared fused vision, are compared for a given type of weather condition.

2 Experimental considerations

The foundation for the simulated tour is a video recording of a real tour as shown in figure 1.

Figure 1: The route used for the automotive scenarios (Mont Pellier).

The road layout and the surroundings in the simulated movies are very realistic and include buildings, trees, open areas and other vehicles. In this way a realistic level of visual workload is achieved.

In the picture below, figure 2, is shown an example or the view that the subjects will see in the experimental evaluation.

Figure 2: A screen-dump from the automotive scenarios.

The situations simulated are the ones shown in table 1.

Scenario Matrix - Automotive				
SEE Function	**No Fog Day**	**Dense Fog Day**	**No Fog Night**	**Dense Fog Night**
With SEE				
No SEE				

Table 1: Visibility conditions in the automotive evaluation.

However, for daylight in clear weather it is not expected that the SEE enhanced vision will be used, as there is no need for it, and this situation has been simulated only without the use of the SEE system just for reference.
Therefore, the table for comparison is the one shown in table 2, indicating day, dense fog, and night, clear weather and dense fog, respectively.

SEE Function	**Dense Fog Day**	**No Fog Night**	**Dense Fog Night**
With SEE			
No SEE			

Table 2: The visibility conditions selected for testing.

In each of the movies a set of selected scenarios has been included in order to prepare situations that the subjects are expected to react to.
The start situation of all the scenarios suggested below is that the test person is driving on a road with a velocity of about 60 km/h. During reduced visibility due to darkness or fog it is possible to see and navigate by the road-side and the white-lining on the road, but, with a reduced visibility of, e.g., 20 meters due to dense fog, the speed allows the person only 1.2 seconds for responding to unexpected objects ahead.
The scenarios used in the evaluation are given below in table 3:

Automotive Events: scenarios which subjects are expected to react to	
Event 1:	A cyclist is driving in the right hand side of the road, a bit far out, so there is a risk that the car may run him down unless it swerves out.
Event 2:	A cyclist is driving in the right hand side of the road – a bit far out – with the risk of being run down. The driver sees the cyclist, and in order to avoid collision he turns the car towards the middle of the road. However, an oncoming car poses a risk of frontal collision.
Event 3:	A person is lying on the road, he does not appear to be hurt, but is immobile.
Event 4:	The driver approaches a road crossing. Another car is approaching from the crossing road. Is the SEE system capable of detecting the other car in spite of the limited side-view?
Event 5:	The driver is approaching a road crossing. At this crossing a cyclist wants to cross the lane of the car. The cyclist is not able to see anyone (due low visibility), but chooses to cross. Reaching the middle of the road, he notices a car coming from the direction opposite to the SEE test driver. The cyclist stops and is now situated in the middle of the lane in front of the SEE driver.
Event 6:	A car is driving in front on the SEE driver. The driver in front becomes uncertain about a possible obstacle on the road. He slows down, but does not activate his breaks, so no stoplights are observed. The SEE driver approaches the car in front, which suddenly breaks. The SEE driver must now break sharply in order not to bump into the car in front.

Table 3: Description of the test-scenarios.

The subjects will experience the scenarios in different kinds of weather conditions and in conditions with or without the SEE enhanced image. The subjects are not all expected to react to all the scenarios, but the expectation is that an adequate number of them will react to the same scenarios allowing analyzing their time of reaction.

3 Test protocol

3.1 Briefing

Confidentiality

The confidentiality agreement was a formality ensuring that subjects would not disclose any information about the SEE project to any third parties. A copy of the confidentiality agreement is in Annex 1.

Background information

The background information sheet contained space for information about name, gender, age, job title, number of years with a driver's license, average driving pr. week (hours) and use of glasses. Please, see the Annex 2. All subjects filled out this sheet right before a briefing and signing the confidentiality agreement.

Visual acuity and contrast sensitivity test

In order to secure an ample sight and contrast sensitivity of the subjects they were all put through a vision test using the Lea Numbers 4 meters chart for the visual acuity and the Lea Numbers[2] contrast sensitivity flipchart test for testing the contrast sensitivity due to the fact that the infrared movies were without colours and it was of vital importance that grey tones could be adequately distinguished. (The data sheet for the test is in Annex 3).

The visual acuity chart covers the normal, the near normal and a part of the moderate low vision visual ranges[3]: specifically from 4/20 to 4/1.6 (20/100 – 20/8 equivalents and in decimal equivalent with 0.20 – 2.5). We saw no need for covering ranges for lower vision (see Annex 4 for information regarding visual testing). We followed the procedures of Lea Hyvärinen on her homepage and the material following the test charts.

The subjects took the test using glasses if they used glasses for driving. The ones who used screen- or reading glasses only, took the test without them, but were allowed to use them when watching the videos on the screen. This was chosen to reduce physical discomfort, such as headache. From the pilot test (Annex 6) we learned that watching the movies could also induce motion sickness.

Technology

In the experiment we used 'The Observer'[4] for collecting data. 'The Observer' is a piece of software developed to collect and analyze any kind of behavioural data. In our case we used it only to collect data. Once all the data were obtained it was extracted from the system and analyzed with the statistical functionality of Microsoft Excel. A 'Concept Board' was connected to the computer. The 'Concept Board' was the input device to be used by the subject as an alternative to a normal keyboard.

The 'Concept Board' is a flat board (no buttons) divided in small squares and is shown in the picture below.

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2 For more detailed information about Lea tests please visit: http://www.lea-test.fi/.

3 See for instance Colenbrander (2001), Measuring Vision and Vision Loss. Available at: http://www.ski.org/Colenbrander/General/references.html#measuring . Similar to chap. 51 in Vol. 5 of Duane's Clinical Ophthalmology, 2001. Other literature about measuring vision also available at the URL indicated.

4 About The Observer and other related products go to Noldus Information Technology at: http://www.noldus.com/

Figure 3: Concept Board.

The experimenter defines areas relevant to the experiment and codes to be sent to another system when the area is activated by a push. We were interested only in detection time and thus did not need a complex setup of ‘The Observer’ or the ‘Concept Board’. On the board one big area was defined. When the subject touched anywhere inside the area a code was sent to ‘The Observer’ system registering the time of the push (minutes, seconds and milliseconds). The picture shows the setup in the experiment room:

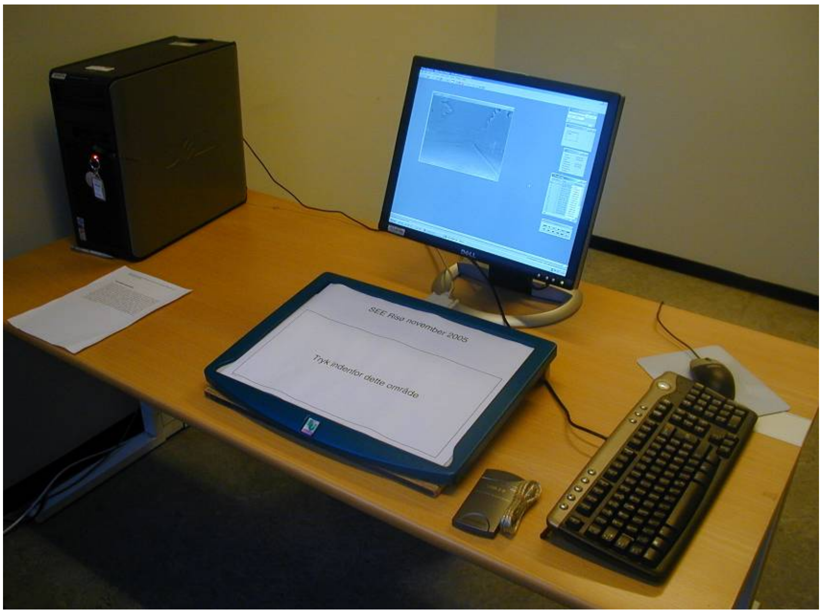


Figure 4: Picture of the setup in the test room.

The size of the window at which the subject looked was approximately 8 inches in order to correspond to the size of the screen expected to be developed for use in a real car.

The experimenter controlled the sessions by means of a keyboard. She was in the room during all sessions, seated out of sight of the subject.

Instruction

The test began with the following instruction:

"Imagine you are a passenger in a car, sitting next to the driver. The car has a new system installed that enhances the visibility by means of a camera that uses infrared light and which is mounted on the car. In that way it becomes possible to detect objects on the road earlier in time as compared to just looking out the wind screen. The video recording from the infrared camera is displayed on a little screen inside the car. Neither you nor the driver is used to using the system, which is why you have agreed that you keep an eye on the road exclusively by using the display, and the driver uses the old fashioned way: looking through the windows. Additionally the driver has reduced eye sight – even in daylight. In order for you to help the driver (and your self!) it is your task to give notice to the driver as soon as possible when you notice something potentially dangerous that you think the driver should be aware of. It could be other road users: pedestrians, drivers, bicyclists and the like. If you see anything that the driver should be aware of please push on the board in front of you. NB: please, always react when you see a bicyclist, pedestrian or other soft road users on the carriageway irrespective of whether you perceive the situation as dangerous or not. Please, say out loud what you are aware of."

The instruction contained the cover story to make the video-viewing more realistic and increase the ecological validity. Ecological validity could be considered low in this experiment due to the lack of a real driving environment, such as a car or a driving simulator. Instructing the subjects to imagine that they were sitting in driver's seat would seem less plausible because they had no control over the events in the videos. Hopefully, the cover story increased the subjects' engagement in the experiment.

The subjects read the instruction by them selves and were asked to explain how they interpreted it. This gave a possibility to correct or to clarify their interpretation of the instruction. They were reminded to explain why they reacted *after* the reaction in order to get the fastest reaction times.

3.2 Test session

During the session the subjects were inspecting the six movies in various order for reducing learning effects (see chap. 4 about experiment design). All potential dangerous situations, especially concerning 'soft road-users' such as pedestrians and cyclist ought to be indicated, and all indications were logged with the related time tag in 'The Observer' system. Following the evaluation the subjects were presented to a brief review of the various movies, but now with indication of having the SEE enhancement system included or not for a given weather situation. During the test the subjects were not told about the running conditions in order avoid bias towards personal preferences, whereas in the final brief review indication of the specific weather situation and having indicated with or without the SEE system is important – as learned from the pilot test - for responding to the questionnaire in the debriefing session.

3.3 Debriefing

Immediately following the test session the subjects were put through a brief interview concerning their subjective impression of the movies. A questionnaire was filled out concerning the general impression of the infrared images per se, and in comparison with the vision without the SEE system. Likewise, the questions were related to perception of objects and obstacles, and perception of terrain features. For comments not covered by the questionnaire there was room for 'Other comment about the infra-red presentations, positive or negative'? The questionnaire is Annex number 5.

4 Evaluation of SEE enhanced vision system

4.1 Experimental design

According to experiences from the pilot tests (Annex 6) changes were made in the test protocol, e.g. changes in the questionnaire, briefing, instruction etc. Due to the larger number of subjects we also made changes in the experimental design. The final version of the experimental design will be described in this section.

From the pilot test we learned that the subjects had problems when answering the questionnaire because they could not distinguish the videos from each other. One way of supporting memory is to make chunks of related data. We decided to vary the order of the videos in a way that would support filling out the questionnaire and at the same time counterbalancing the conditions to account for order effects. The videos were chunked into two: one chunk representing the with-SEE videos (even numbers) and one without-SEE (odd numbers). Within the chunks we varied the videos systematically as much as possible. The numbers in table 4 corresponds to the numbering used in the pilot test, in which we also used the LWIR and SWIR movies:

Videos without SEE	**Videos with SEE**
1,3,7	2,4,8
1,7,3	2,8,4
3,1,7	4,2,8
3,7,1	4,8,2
7,1,3	8,2,4
7,3,1	8,4,2

Table 4: Basic variation of videos[5]*.*

The variation was repeated to have enough for 20 subjects. In every second row the even and the odd numbers were switched. That way half of the subjects began with the three videos with the SEE system and ended with the three videos without the SEE system and vice versa

5 In table: 1 = no fog, night, - SEE; 2 = no fog, night, + SEE; 3 = dense fog, night, - SEE; 4 = dense fog, night, + SEE; 7 = dense fog, day, - SEE; 8 = Dense fog, day, + SEE

for the other half of the subjects. The order of the videos for each subject is shown in table 5 below.

	Grey background = with SEE, white = without SEE					
Subject A	1	3	7	2	4	8
Subject B	2	8	4	1	7	3
Subject C	3	1	7	4	2	8
Subject D	4	8	2	3	7	1
Subject E	7	1	3	8	2	4
Subject F	8	4	2	7	3	1
Subject G	1	3	7	2	4	8
Subject H	2	8	4	1	7	3
Subject I	3	1	7	4	2	8
Subject J	4	8	2	3	7	1
Subject K	7	1	3	8	2	4
Subject L	8	4	2	7	3	1
Subject M	1	3	7	2	4	8
Subject N	2	8	4	1	7	3
Subject O	3	1	7	4	2	8
Subject P	4	8	2	3	7	1
Subject Q	7	1	3	8	2	4
Subject R	8	4	2	7	3	1
Subject S	1	3	7	2	4	8
Subject T	2	8	4	1	7	3

Table 5: Order of videos for all subjects.

4.2 Subjects

In a previous report about operational requirements[6] we have reported an analysis of data from three European databases (from Denmark, Sweden, and Germany) and a US database concerning road accidents. The four databases showed that the four countries mentioned have very nearly the same proportion of road accidents due to fog or darkness relative to the overall amount of road accidents. Danish drivers and driving conditions with regard to relative accident risks in fog and darkness are therefore representative of this sample of countries.

Subjects were recruited from Risoe National Laboratory, 8 women and 12 men. Age range: 26 – 64; mean = 49. All subjects had had a driver's license for between 8 and 45 years (mean: 30) and drove on average 9,7 hours a week. All subjects drove regularly in darkness, especially in wintertime and more seldom in fog - as would be expected. Twelve of them used glasses when they drove. The specifications of the subjects are collected in table 6.

There are no special issues to report regarding the visual tests. All subjects had normal visual acuity and contrast sensitivity.

6 SEE deliverable D1.5, Operational Requirements

Subject	gender	age	job	Number of years with driver's license	Avg. driving pr. week (hours)	Uses glasses for driving?
A	Male	64	Senior scientist	45	10	Yes
B	Male	45	Senior scientist	27	5	No
C	Male	37	Senior scientist	19	3	Yes
D	Male	58	Chief consultant	40	10	No
E	Male	58	Laboratory masterman	40	3	Yes
F	Female	60	Assistant	42	8	No
G	Female	59	Laboratorian	41	17	Yes
H	Female	49	Special consultant	30	8	Yes
I	Female	57	Head of secretariat	39	7	Yes
J	Male	40	Development engineer	20	12	No
K	Male	37	Senior scientist	19	7	No
L	Male	63	Engineer	45	15	Yes
M	Male	46	Finance assistant	26	7	Yes
N	Female	59	Deputy manager	45	14	Yes
O	Female	42	Secretary	24	10	Yes
P	Male	32	Engineer	11	5	No
Q	Male	54	Development engineer	36	14	Yes
R	Female	41	Finance assistant	21	14	Yes
S	Female	26	Trainee	8	15	No
T	Male	48	Production manager	30	10	No

Table 6: Subject specifications.

4.3 Results of the time of reaction test

Figure 5 shows an example (night with fog using the SEE system) of the complete logging of the reactions of the subjects for perceived hazardous situations. The logging of all weather situations may be seen in Annex 7.

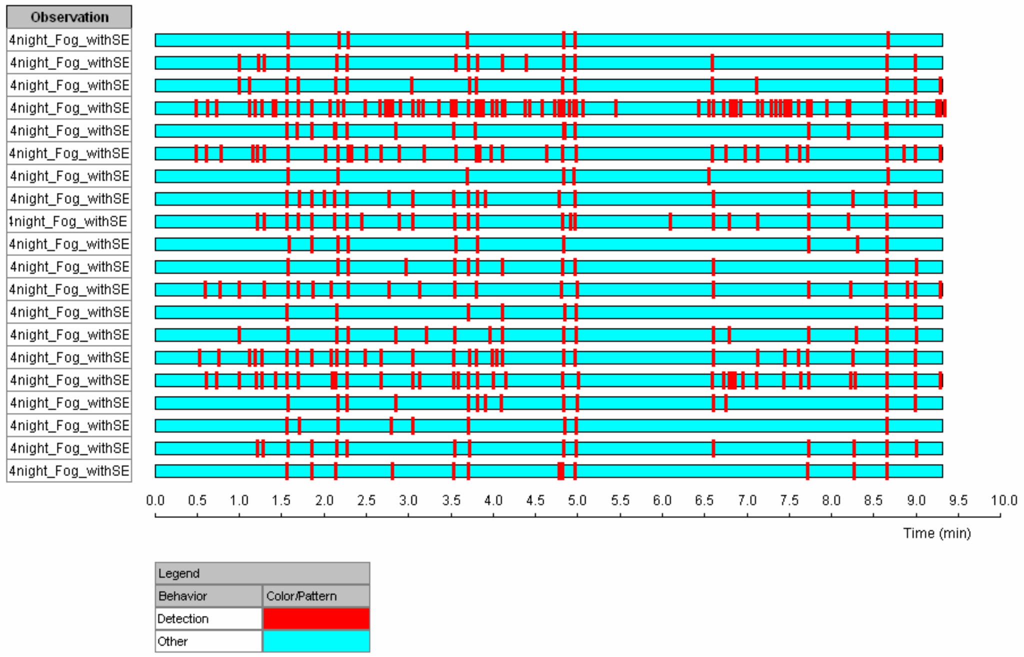


Figure 5: Illustration of reaction times in the night, fog, with SEE for all subjects.

Based on these loggings, scenarios responded to by nearly all of the subjects have been selected. The selected scenarios are scenarios 1, 2, 3 and 5, respectively – please see Table 3 above.

For each weather-condition a time window has been defined. The time window begins at the time at which the situation reacted upon may be spotted and ends when the situation is passed by the test car. The time of reaction for each of the subjects within this time window has been recorded, and the time distribution of reactions for each weather situation related to using or not using the SEE system has been compared. The level of significance was determined by assessing the difference in mean reaction times between the SEE and the no-SEE trials under the same visual conditions, using the repeated measures *t*-test (also known as a paired samples or related samples test).

For night-time, clear weather condition, the results for all four scenarios show an advantage in using the SEE system: drivers detect the obstacle earlier and may avoid a dangerous situation. For scenario one and two the subjects' detections using the SEE system is more than 0.5 sec earlier than the detections made without the SEE system. However, the difference is not statistically significant – primarily due a relatively large variance in the difference, for each person, between the SEE and no-SEE condition.

For scenarios 3 and 5, however, the situation is more well-defined, involving a man lying on the road and a cyclist crossing the road. Here it is obvious to everybody that this is a safety-critical situation. As expected, therefore, all subjects reacted to these situations promptly, resulting in a relatively small variance in the difference between the SEE and no-SEE condition. The time difference in variance ranges from 0.9 to 1.4 sec and the results of these observations show a statistically significant improvement by using the SEE system.

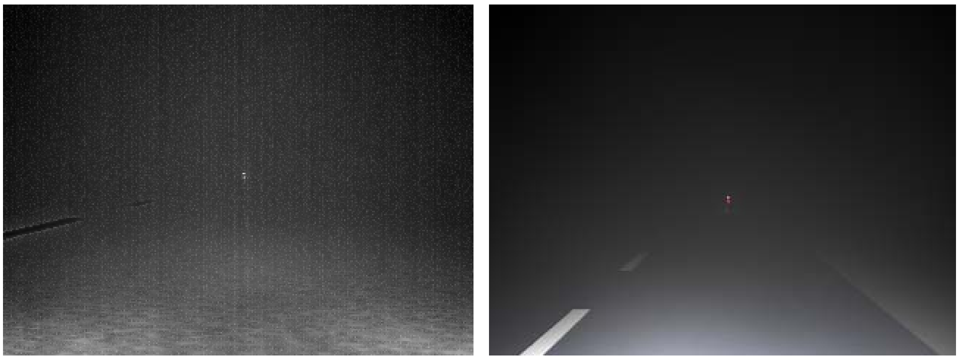
In foggy weather the outcome is very different. The analysis shows a *disadvantage* in using the SEE system – as summarised in Table 7. As we shall explain in the discussion section below (and documented in detail in Annex 8), a detailed analysis of the parameterization of the simulation has shown that the lack of sight effectiveness enhancement is most likely due to a non-optimal selection of parameterization issues in the simulations

Scenarios/events	Day, fog		Night, no fog		Night, fog	
	Without SEE	With SEE	Without SEE	With SEE	Without SEE	With SEE
1: Cyclist	92.74[7]	93.62	88.71	88,06	92,73	93,45
	Disadvantage (= -0.88) significant ($p = 0.04$)		Advantage (= 0.65) not significant ($p = 0.30$)		Disadvantage (= -0.72) significant ($p = 0.0002$)	
2: Cyclist and car	126.46	127.66	125.24	124,65	126,53	127,85
	Disadvantage (= -1.2) significant ($p = 0.0002$)		Advantage (= 0.59) not significant ($p = 0.12$)		Disadvantage (= -1.32) significant ($p = 0.003$)	
3: Man lying on road	297.95	297.49	298.13	296,77	297,92	297,67
	Advantage (= 0.46) not significant ($p = 0.10$)		Advantage (= 1.36) significant ($p = 0.0001$)		Advantage (= 0.25) not significant ($p = 0.19$)	
5: Crossing cyclist	517.77	518.33	518.25	517,37	518,84	518,49
	Disadvantage (= -0.56) significant ($p = 0.0004$)		Advantage (= 0.88) significant ($p = 0.0006$)		Advantage (= 0.35) significant ($p = 0.01$)	

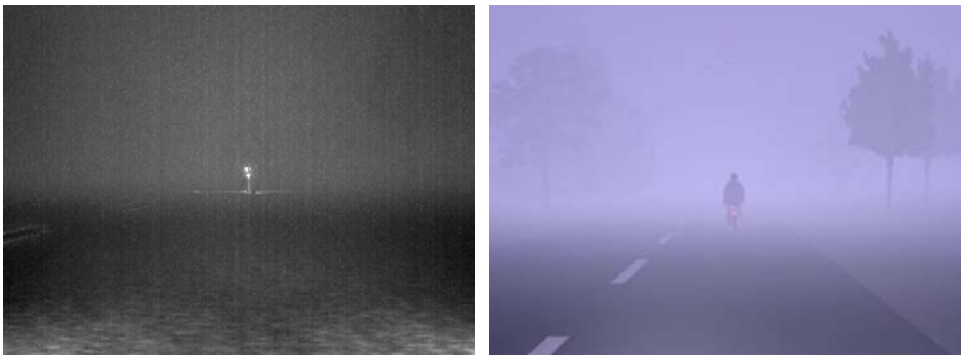
Table 7: Detection times in secs with indication of advantage/disadvantage of the SEE system

Examples showing the same frame (scenario 1) with SEE at the left and without SEE at the right:

Time 01:33; Night, clear weather. Cyclist is completely visible with SEE (left), but only a back-light is visible without SEE (right)



Time 01:33; Night with fog. The colour of the rear light gives an advantage in the condition without SEE (right).



Time 01:34; Daylight with fog. The silhouette of the cyclist is more visible without SEE (right) than with SEE (left).

4.4 Results of the questionnaire

Each subject was asked, following his or her trial, to fill out a questionnaire – the text of which is shown in Annex 5.

Some of the questions are of general character – such as how good the infrared information was in order to perceive the situation and about potential problems in not having colours in these pictures. In addition, this group of questions ask the subjects explicitly about the performance in general of the SEE system during fog and during night-driving.

Another group of questions are related to the perception of objects or obstructions on or near the road, and the third and final group was related to the environment and the road itself.

At the end of the questionnaire space was left for specific comments, which the test person wanted to stress, and which were not sufficiently covered by the specific questions.

Figure 6 shows the results of the general questions. For perceiving the information given by the infrared picture 75% were satisfied with the presentation, whereas 15% were not happy, and 10% were neutral. The percentage for satisfied is taken as the number of persons agreeing or completely agreeing with the question as compared to the total number of subjects, whereas the percentage of not happy persons is taken as the number of disagreeing or completely disagreeing. The remaining part is the neutral ones.

For the problem related to the lack of colours the response was completely balanced by 45% seeing it as a problem or as no problem, respectively; 10% was neutral.

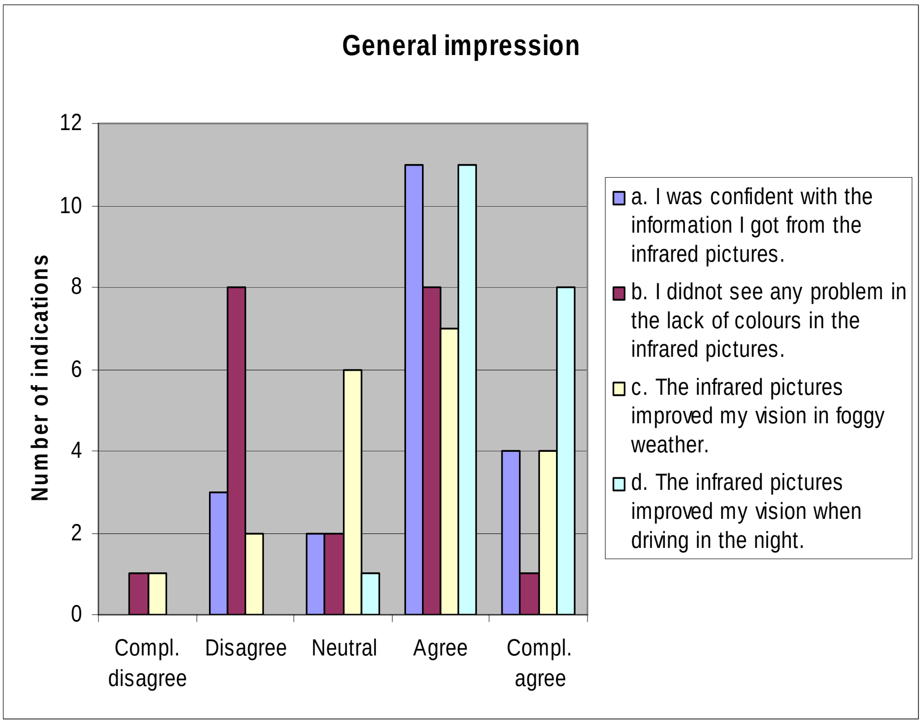


Figure 6: The general impression of the SEE system.

The subjective opinions about improved vision in foggy weather by using the system was 55% in favour of the system, 15% was not convinced, and 30% had no opinion.

For night-driving in clear weather, however, 95% agreed that the system improved the vision, none disagreed, and 5% was neutral.

Figure 7 gives the responses about the perception of objects and obstacles.

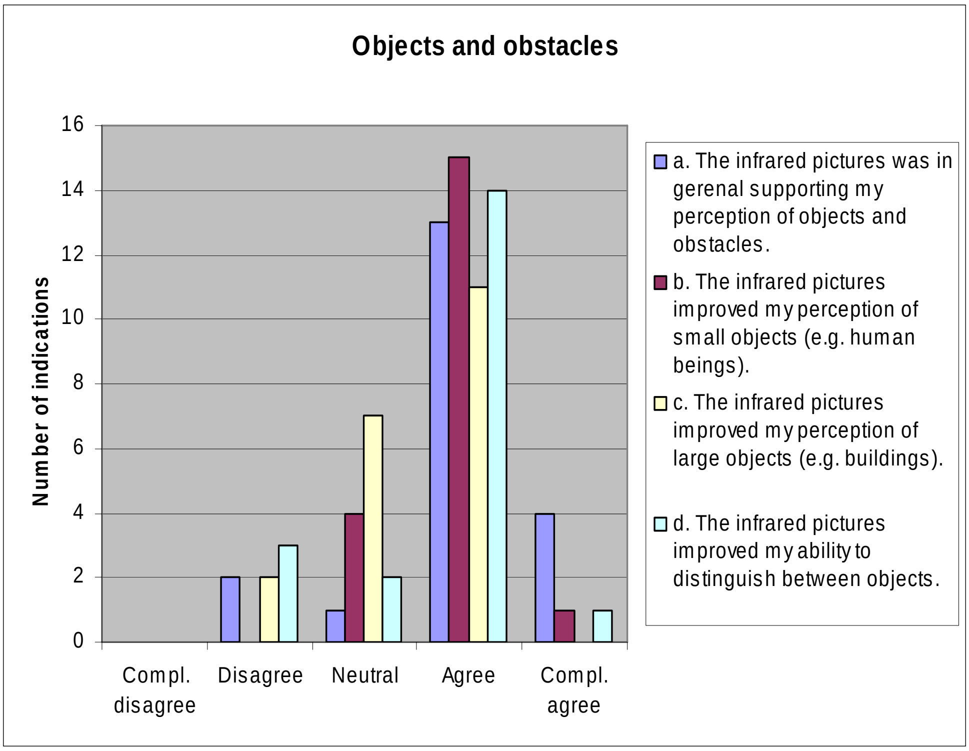


Figure 7: The impression concerning perception of objects and obstacles.

For the support of perception of obstacles in general 85% found the system helpful, 10% did not agree to this, and 5% had no opinion about it.

As the infrared is mainly a detection of heat radiating object, is it expected to be especially helpful for, e.g. human beings and animals, and in this respect 80% agreed to this support, nobody disagreed, and 20% had no specific feelings for this.

For larger object, such as houses, 55% saw the system as a help, 10% disagree, and 35% remained neutral.

Finally, for the ability to distinguish between objects, i.e. to be aware of what is in front of you, 75% found the SEE system acceptable, 15% was not satisfied, and 10% were neutral.

Figure 8 gives the response for getting adequate information about the environments of the road, like being aware of side- and cross-roads and other objects in the neighbourhood.

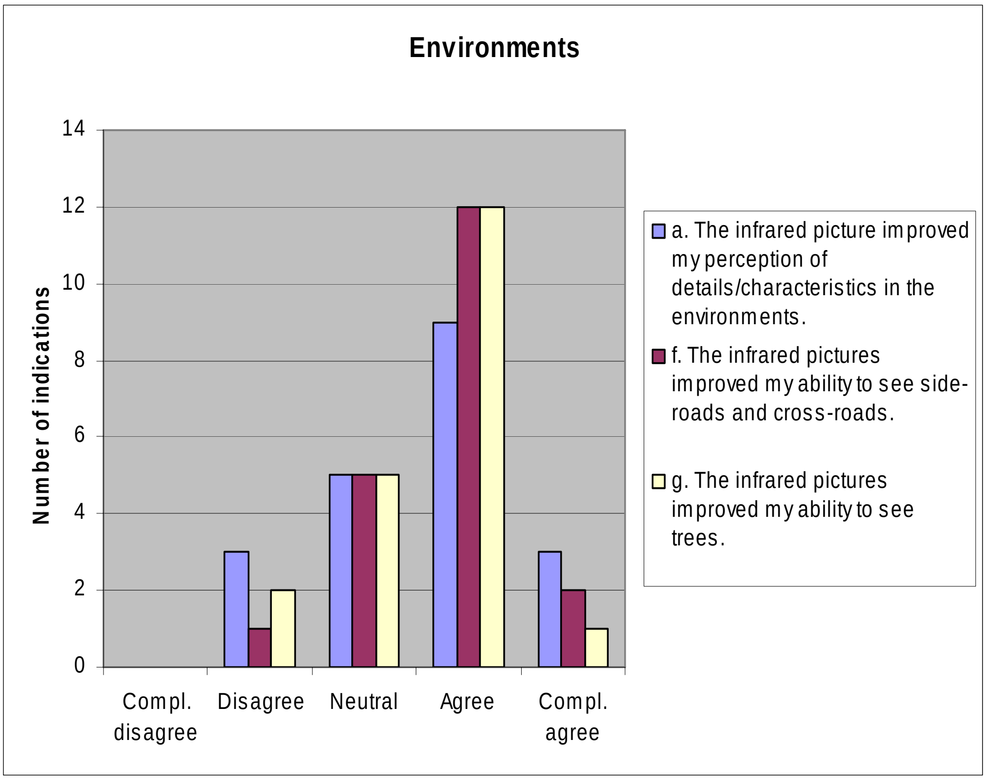


Figure 8: The impression concerning the environments of the road.

The infrared improved the perception of details in the environments was agreed by 60% of the test persons, 15% did not agree to this, and 25% were not sure about this improvement.

For the ability to see more specific issues, like the notice of side-roads and cross-roads 70% agreed to have improved vision, only 5% felt the opposite, and 25% were not sure.

With regard to an improvement to see trees, 65% of the participants agreed, 10% disagreed and 25% were unsure.

Finally, Figure 9 gives the subjective feeling concerning the terrain, i.e. the road its and its related road signs, like white-lining and traffic signs.

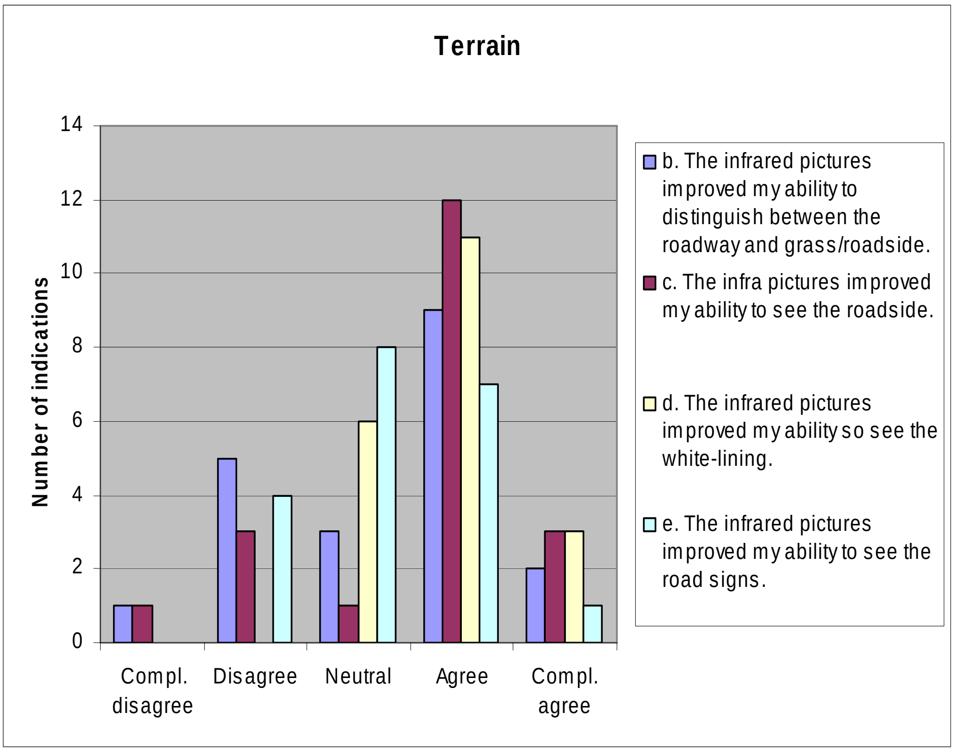


Figure 9: Impression about the ability to manoeuvre the car on the road.

For the ability to distinguish between the roadway and the surroundings like grass, 55% felt that the SEE system improved this ability, 30% did not, and 15% were not sure about it.

For directly being able to follow the roadside 75% felt themselves supported by the SEE system, 20% did not feel this support, and 5% had not reflected about this issue.

The white-lining on the road seems to be neatly highlighted by the SEE system, as 70% found themselves better capable of following the white-lining, which is normally a very important support for drivers during night or in foggy weather, none had the opposite experience, and 30% did not recall the existence or non-existence of this effect.

The improvement in noticing the road-signs was not as significant, as just 40% felt this issue improved by the SEE system, 20% did not feel any improvement, and 40% more or less had not noticed the road-signs neither with nor without having the SEE system available.

The questionnaire has been designed in a manner that even though the way of addressing it is to indicate agreement or lack of agreement with given statements, the agreement will anyway indicate confidence with the system and disagreement the opposite. Therefore, it is possible to use the responses to the questionnaire to unveil the overall satisfaction with options offered by the SEE system. This is indicated in Figure 10.

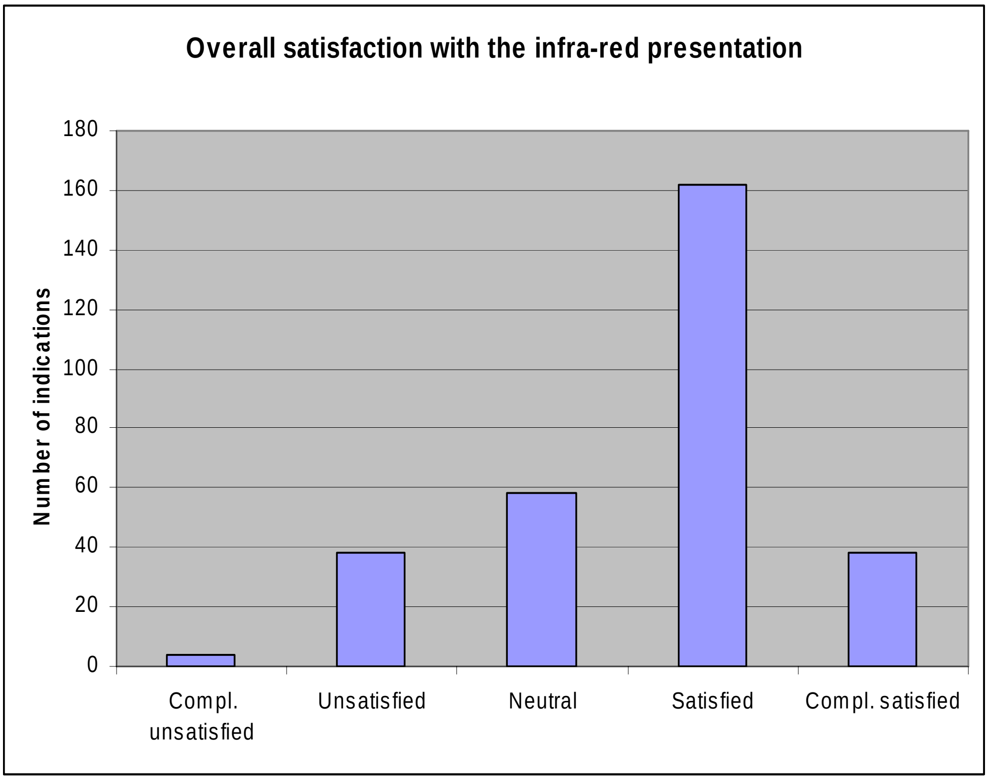


Figure 10: The overall satisfaction with the options offered by the SEE system.

The subjective response indicates that 67% of the test persons find that the SEE system in fact was promising as a tool for improving the visibility conditions under otherwise reduced visibility as well for object detection as for manoeuvring , 14% did not find any improvements, and 19% couldn't decide if they experienced any improvement or not.

4.5 General comments from the sessions

The subjects were encouraged to write about their opinion towards the videos in the questionnaire. Among the comments were the following:

"No advantage by the infrared pictures in foggy weather, neither during night nor day. In contrast, it was a very positive experience to have the infrared pictures for normal night driving".

"Good during night, not very useful in fog; may even be dangerous due to a false feeling of safe driving".

"Infrared during night without fog: definitely an advantage; infrared in foggy weather: no advantage".

These comments correspond to the comments and spontaneous remarks made during the sessions. Almost all subjects remarked that they felt like the car was driving faster when they encountered the videos with SEE and fog. This problem is probably due to an unconfident feeling of going too fast in relation to the reduced visibility.

The issue of missing colours in the SEE videos was commented by almost all subjects. According to the subjects the missing colours made it difficult to figure out whether a light was streetlight, light from oncoming cars, cars driving in front or bicyclists. However, the problem did not seem to be of great importance. Many of the subjects got used to it and learned to distinguish between for example head– and taillight from other visual cues, such as size.

Many subjects had trouble interpreting different details in the images - especially in the beginning of a session. Some made misinterpretations, e.g. could not see if it was a motorcycle or a bicycle. At some times in the videos the car drives into a branch from a tree standing near the road, many subjects wondered about what it was. A couple of times the man on the road was not reacted to because they could not see what it was. It was clear that they had, in fact, noticed the man because they commented on it verbally.

Comments made to the night-time, clear weather, with SEE conditions was among other things: “There is more perspective in this one”, “Now I can se very far ahead.”, “This one is tolerable [a remark made by a subject who got very car sick]”, “This one is easier to look at than the other ones.”, “The visibility is fine here.”, “Well, in spite of the fact that it is black and white, you can actually see something.”, “I notice things here, that I did not notice in the other movies.”. “It is hard to tell distances, it would be nice to have an indication of distance as you do when you are on a boat”.

Comments regarding the videos with SEE in fog were opposite: “I would have been better-off with regular fog.”, “Now there is really a lot of fog.”, “This does not look good.”, “This is really ugly.”, “Oh, this does not look nice.” These rather negative comments never became especially concrete. Many of the subjects did not like the look of the images because of visual noise but apart from the missing colours and the impression of driving very fast it seemed to be a ‘feeling’ towards the images that not necessarily had to have an influence on the reaction times.

5 Discussion

The results from the simulations did not meet our expectations that the SEE system would be clearly advantageous during foggy weather conditions

In fact, when we look at the simulations of fog during night and during day (see Table 7) the analysis shows a statistically significant disadvantage in using the SEE system for 5 out of 8 obstacle events, one event having a significant advantage to SEE and two events a non-significant advantage. At the time when the simulation trials were prepared and carried out, the lack of advantage of the SEE system was a puzzle to the experimental team.

5.1 Advantage of Prototype system contradicting the simulated system in foggy conditions

It was known from informal test trials with the SEE prototype that an obvious advantage of the enhanced vision system could be observed during foggy conditions.

Figure 11: Image from the SEE prototype

A series of test trials have been carried out by SEE partners Zeiss and BMW, using a prototype of the “real” SEE system. The prototype of the SEE system performs much better than the system shown in the simulations used in the experimental trials reported above. In Fig. 11-13 we show images from the SEE prototype. The two images at the top are the LWIR and the SWIR. The lower right image is the fusion images shown to the driver and the lower left image, the “Driver’s sight”, represents the condition without the SEE system. In contrast with the simulated videos – as illustrated above – objects (see pictures in previous section) are visible earlier in the fusion compared to the driver’s sight.

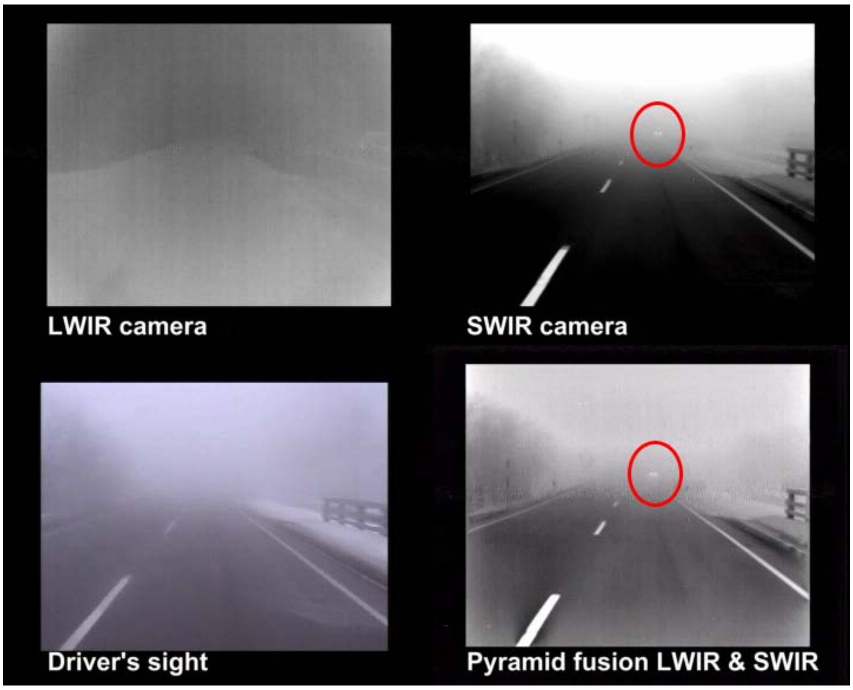


Figure 12: Image from the SEE prototype

Figure 13: Image from the SEE prototype

As is demonstrated in the images in Fig. 11-13 copied from the trials conducted by Zeiss and BMW, the results of the automotive trials are not representative of the capability of the SEE system.

5.2 Parameter selection

After the trials reported above had been conducted, renewed efforts have been made to identify the sources of the difference in performance between the SEE prototype and the simulated one. These efforts seem to have identified the reasons why the simulations have been far from optimal with regard to bringing out differences between using the SEE and not the SEE system during foggy conditions. It has turned out that the parameterization selected for the simulations used in the automotive simulations has not been optimal – but has in fact reproduced a type of fog that puts the SEE system at a distinct disadvantage. Moreover, the temperature difference between the simulated, surrounding fog and the simulated objects (cyclists) has been too small as compared with real conditions. This means, again, that the simulations have not produced an enhancement that would be typical and would be expected.

In table 8 below simulated images are shown which have been recomputed according to new parameters, enhancing the object/background temperature difference. The parameterization for fog is the same (advective fog). Table 9 shows images re-computed with a different kind of fog (radiative fog). Please, refer to Annex 8 for details. Left columns are images from the simulations evaluated in the present report and right columns the re-computations.

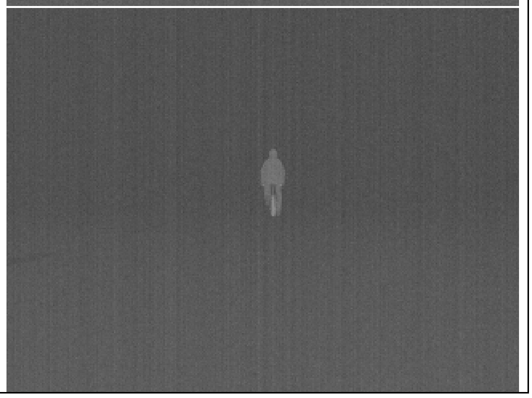
Time	Simulations used in trials	New simulations, colder background
93 s		
93.6 s		
94 s		

Table 8: Comparison of trial simulations and new simulations with advective fog and colder background

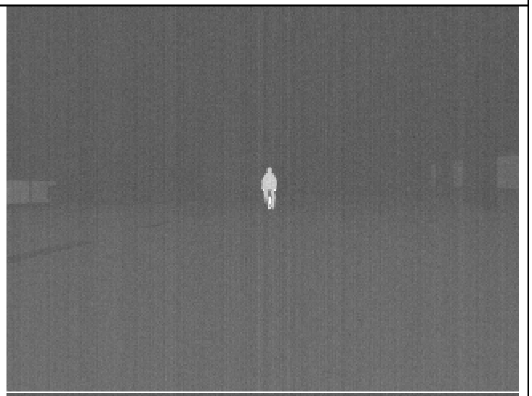
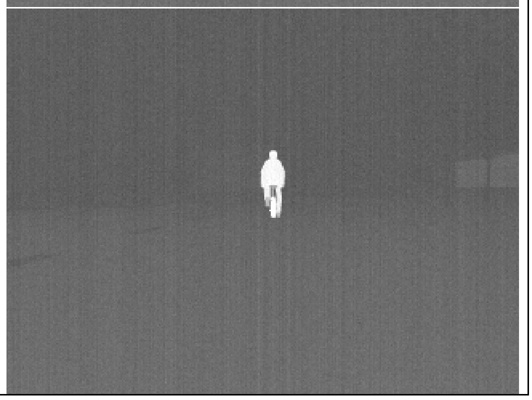
Time	Simulations used in trials	New simulations, colder background
93 s		
93.6 s		
94 s		

Table 9: Comparison of trial simulations and new simulations with radiative fog and colder background

6 Conclusion

The SEE system built for sight effectiveness enhancement has been evaluated for the automotive domain by objective measurements based on subjects' (N=20) response to hazardous situations during a simulated test-drive and on subjective impressions about the simulated system elicited from test subjects.

The tested system was a simulation of the real SEE system designed for supporting drivers under reduced visibility conditions. The evaluation has focused entirely on the quality of the images with regard to providing improved traffic information. The evaluation is based on a comparison between having the SEE system available and not available in three weather situations: day with intense fog, night with intense fog, and night in clear weather.

Analysis of test subjects' response to hazardous situations, especially concerning care of 'soft' road-user like pedestrians and cyclists was targeted on a selected set of situations or events: Four out of six possible scenarios were selected for the analysis as nearly all the test persons have responded to these scenarios. The two remaining scenarios were too complex to allow for a clearly defined time of a reaction

For night-time, *clear* weather condition, the results for all four scenarios show an advantage in using the SEE system. For scenario number one, the bicycle on the road, and number two, the combined bicycle and car scenario, the drivers using the SEE system gives on average a more than 0.5 second earlier reaction – but this was still below statistical significance. For scenarios 3 and 5, a man lying on the road and a cyclist crossing the road (highly safety-critical situations), the time differences range from 0.9 to 1.4 sec and the results of these observations are statistically significant improvements by using the SEE system.

In foggy weather the situations is somewhat different. The analysis shows, in some situations, a disadvantage in using the SEE system. Nevertheless, the advantage of the system for night vision comes through also with fog where the SEE system shows a statistically significant advantage for scenarios 3 and 5.

The results of the simulated SEE system during user evaluation trials are disappointing. Comparison of simulation videos and the images taken from pilot trials with the SEE prototype shows obvious gains in visibility with the SEE system. Moreover, subsequent analysis of the parameterization used to make the simulations indicates that the lack of sight effectiveness enhancement is due to very unfavourable selection of parameterizations: the simulations have been based on the worst potential case of fog and the worst possible thermal contrast.

Results from the questionnaire responses by the test subjects show largely positive reactions. A great improvement by using the SEE system for night driving in clear weather is indicated by 95% of the test persons. However, although the objective test showed no positive effect of the SEE system during foggy weather 55% of the test persons agreed that the system improved their vision.

7 Annexes

Annex 1: Confidentiality Agreement

CONFIDENTIALITY AGREEMENT

between Risoe National Laboratory and___________________________________

for the purpose of Risoe’s publications in connection with the project, ”SEE, Sight Effectiveness Enhancement. 5th PCRD Contract IST-2001-38228”, the undersigned agrees to keep knowledge and experiences with this project, that is obtained from Risoe, strictly confidential.

He or she will neither reveal the information to third party nor in any other way, directly or indirectly, use nor disclose the information.

This agreement is in accordance with the confidentiality agreement that employees at Risoe National Laboratory signs in connection with employment.

Date:

Signature: ____

Company: ____

Address: ____

Annex 2: Background information

Name:

(Your information will be treated confidentially – Your name will not appear in the report or elsewhere)

Gender: Male ☐ Female ☐

Year of birth: __ __ Age: __ __

Job title:

Have had a driver's license for ______ years

Drives a car on average approx. ______ hours pr. week.

If you only drive occasionally, please specify how often you drive (if you for instance do not have a car but burrows one from time to time):

Other comments regarding your routine as a driver (do you have experience as a commercial driver or do you drive a heavy vehicle, motorcycle etc.?):

How often do you drive in darkness?

May we contact you again if we need participants for other projects?
Yes ☐ No ☐
If yes, please state one of the following: phone number, address, e-mail address:

Background information continued (info about vision)

Do you use glasses or contact lenses? Yes ☐ No ☐

If yes, which optical strength? Right eye____ / Left eye ____

Do you have structural eye defect or other information about your vision? Please elaborate:

Annex 3: Data sheet from vision tests

ParticipantID: ___________

Results from visual acuity test:

Both eyes (with glasses) ____/____, decimal: 6 meter equivalent: ____/____

Results from contrast sensitivity test:

3 meter:

1,5 meter:

Notes:

Annex 4: Vision tests

There are different types of visual tests, e.g. visual acuity, contrast sensitivity and colour tests. In each category of vision test variations of the test exist. For instance when you want to buy a visual acuity test, you are presented with different types measuring different ranges of visual acuity and building on different but related principles. Even the symbols on the tests (also called optotypes) are different, e.g. letters, numbers, Landolt C's or tumbling E's (E's turned in different directions). Charts with numbers are often used with illiterate adults or children old enough to know the numbers. Letter charts are mostly used on normal literate adults and charts with drawings or shapes such as apples, circles, hearts etc. are used for small children. The standards of the distances of the test also vary. A 6 meters test is often used but obviously a lot of space in the office is needed for such a test. 3 meters tests are used primarily to children since they concentrate better when they stand closer to the test. Vision testing is used in medical domains with the objective of identifying illness. They are also used, as we did, for the purpose of evaluating the visual capabilities of tests persons before a scientific experiment and they are used by an optician to determine whether a person needs glasses etc. Which tests should be used and how they should be used is naturally dependent on the objective of the test. Obviously, a test conducted to identify more or less serious illnesses should be conducted much more carefully and with another test than for our purpose for instance.

The visual acuity test

Visual acuity tests determine the smallest details of high contrast that a person is able to see. The charts have large numbers or letters on the top lines and the sizes becomes gradually smaller on the lines below.

Normal vision is often considered to be 20/20 but in fact normal vision covers a larger range. The definition of the range of normal is from 20/25 to 20/12.5 (or 0.8 to 1.6). (Colenbrander, 2001). On our 4 meter test it corresponds to 4/5 to 4/2.5. The 4 meters test covers the ranges of normal, near normal and a part of the low vision range - from 4/20 to 4/1.6 (20/100 – 20/8 and .20 – 2.5 equivalent). Fortunately, the notations and their equivalents in other notation-forms are written directly on the test chart, making it easy to switch between the notations without having to make calculations. Since notations differ in the USA and Europe, we chose to keep the notation for the 4 meters test and have the decimal equivalent also.

We chose the Lea Numbers[7] test for 4 meters. The tests were conducted as prescribed in the material following the test and also on Lea Hyvärinen's web-page. The test can be used both with and without a light box. We used it without. We had a spotlight pointing at the test. All lamps in the room were turned on and the curtains were opened. This could cause a difference in the light level in the room, since we could not control the weather conditions outside, however, for our purpose we believe that the considerations made were sufficient.

7 Lea Hyvärinen has developed sets of vision tests. A description of her tests can be found at http://www.lea-test.fi/.

The contrast sensitivity test

Contrast sensitivity tests measures the lowest level of contrast the visual system is able distinguish, that is, the ability to tell the difference between the object and the background. A person who has normal vision in a visual acuity may do worse in a contrast sensitivity test and it may explain why a person experiences difficulties in seeing even though he or se does well in a visual acuity test. The contrast sensitivity test may give supplementary information to the visual acuity test. For instance Hyvärinen (http) suggests that the contrast sensitivity test should be considered in occupational health e.g. when the work involves driving in reduced visibility conditions or visual surveillance in aviation or diagnostic work in medicine etc. That is, all types of work, that relies on being able to distinguish low contrast details.

We used the Lea Numbers flipchart and as with the visual acuity test followed the prescribed procedures. The flipchart is a small book with one line of numbers on each page. The contrast is decreasing from page to page but the size of the numbers remains the same.

http://www.ski.org/Colenbrander/General/references.html#measuring

http://www.lea-test.fi/

See also:

Frisén, Lars (1990): Clinical Tests of Vision. Raven Press. (E.g. Chap. 2: Measuring Vision and Chap. 3: Visual Acuity.)

Annex 5: Questionnaire

	Compl. disagree	Disagree	Neutral	Agree	Compl. agree
1. In General					
a. I was confident with the information I got from the infrared pictures.					
b. I did not see any problem in the lack of colours in the infrared pictures.					
c. The infrared pictures improved my vision in foggy weather.					
d. The infrared pictures improved my vision when driving in the night.					
2. Objects and obstacles.					
a. The infrared pictures were in general supporting my perception of objects and obstacles.					
b. The infrared pictures improved my perception of small objects (e.g. human beings).					
c. The infrared pictures improved my perception of large objects (e.g. buildings).					
d. The infrared pictures improved my ability to distinguish between objects.					
3. Terrain					
a. The infrared picture improved my perception of details/characteristics in the environments.					
b. The infrared pictures improved my ability to distinguish between the roadway and grass/roadside.					
c. The infra pictures improved my ability to see the roadside.					
d. The infrared pictures improved my ability so see the white-lining.					
e. The infrared pictures improved my ability to see the road signs.					
f. The infrared pictures improved my ability to see side-roads and cross-roads.					
g. The infrared pictures improved my ability to see trees.					

Other comments about the infra-red presentations, positive or negative?

Annex 6: Pilot test of LWIR, SWIR and Fusion

Movie Simulation

Due to technical issues in the data-fusion of the LWIR and the SWIR images, the videos representing the foggy weather conditions had a doubtful perceptual quality. The movies were sent back and forth between Oktal and Risoe in order to find a way for limiting visual noise in the movies. Different fusion algorithms were tried, yet, in spite of the hard work from Oktal to enhance the quality of the data-fusions, problems still remained in the end.

It became clear, after concluding the evaluation and after a thorough exploration made jointly by the partners of the SEE project and especially Oktal that the problems existed because of parameter setting. This issue has been described in the discussion and in annex 8.

Objectives of the Pilot test

We decided to test whether the data-fusions had a quality good enough to stand alone to be compared with the no-SEE foggy weather conditions, or whether we had – in addition - to compare the no-SEE videos with the LWIR and SWIR individually. We had a choice between two alternative experiment designs: One in which we used only the data fusion and one where we had to include the LWIR and SWIR in order to have the best possible means of comparing the qualities of the infrared images. The optimal solution would be the first option since we would only use 6 videos as opposed to 10 in the second option. As illustrated in table 1 below, the straight lines represent comparisons to be made when all videos are used – 7 comparisons. If the data-fusions were better or at least just as good as the LWIR and the SWIR videos, four of the comparisons could be excluded (represented by dashed, straight lines) leaving only 3 comparisons and 6 videos (number 5, 6, 9 and 10 would be cut out). This would reduce the time of a given session with approximately 40 minutes, and reduce the load on the subjects. Additionally, an analysis of the qualities of the LWIR and SWIR movies would not have been straight forward. How the image quality of a fused image is perceived by the subject is not likely to be obtained from analyzing positive and negative qualities of the original images per se. In a worst case scenario we would have to use the LWIR and SWIR movies and figure out a sound way of getting around the problem.

The objective of the pilot test was also to function as a standard pilot test where the procedures of the experiment were tested before the actual evaluation.

We conducted 6 pilot tests comparing the LAP (Laplacian Pyramid algorithm) data-fusions with the long wave and the short wave videos[8]. The comparisons made in the pilot test are illustrated with the curved, dashed lines in table 1.

8 All videos were originally fused by means of the Gradient Pyramid (GRD) algorithm, The LAP algorithm was an improvement with regards to the videos with fog compared to the GRD. The fusion was done by means of the image fusion computer developed by Galileo-avionica (see WP 4). In the night, no fog condition, the early fusion based on GRD had a very good quality, as will be evident in the conclusion of the paper, and for that reason no alternative algorithms were tried.

	No Fog Night	FOG					
		NIGHT			DAY		
		Fusion	LWIR	SWIR	Fusion	LWIR	SWIR
- SEE	1	3			7		
+ SEE	2	4	5	6	8	9	10

Table 10: Overview over the comparisons of the videos

Experimental design

The method was a repeated measures design (all subjects were presented with all of the 6 videos representing Fusion, LWIR and SWIR, night and day.). As described in a previous paragraph the contents of the videos were identical – merely added different weather conditions. The risk of a subject recognizing specific elements and knowing when specific events would appear was high. In order to account for learning and order effects the videos presented to the subject were varied according to the Balanced Latin Square[9].

The Balanced Latin Square is used as a way of varying the experimental variables systematically. If we, for instance, as in this pilot test, have 6 different types of stimuli (the videos) and six subjects in the experiment we would vary them as shown in the table below, read from left to right:

	Order of stimuli					
Subject 1	1	2	6	3	5	4
Subject 2	2	3	1	4	6	5
Subject 3	3	4	2	5	1	6
Subject 4	4	5	3	6	2	1
Subject 5	5	6	4	1	3	2
Subject 6	6	1	5	2	4	3

Table 11: Example of Balanced Latin Square

9 The Latin Square is a mathematical theory which is often used in experimental psychology. Consult for instance: http://www.cut-the-knot.org/arithmetic/latin_intro.shtml or http://bill.psyc.anderson.edu/exdes/ex8.htm for a further introduction.

As it appears, number two never follows number one more than once across the subjects. This is true for all numbers. The same number never appears directly after another specific number more than once or in other words the same stimuli variable appears after another variable equally often.
Translated into the numbers from table 1 on page 11 the order of videos for each subject in the pilot test is shown in table 3:

Subject	**Order of videos**					
A	4	5	10	6	9	8
B	5	6	4	8	10	9
C	6	8	5	9	4	10
D	8	9	6	10	5	4
E	9	10	8	4	6	5
F	10	4	9	5	8	6

Table 12: Order of videos in pilot test[10].

Subjects

The six subjects were recruited from both inside and outside Risoe National Laboratory and aged from 27 to 62 (avg: 45). They had a drivers license from seven to 44 years (avg: 25) and drove on average 9 hours weekly. All of them drove regularly in darkness or fog.

Stimuli

The videos used in the tests were: LWIR, SWIR and LAP data-fusion in the dense fog daytime condition and LWIR, SWIR and LAP data-fusion in the dense fog night time condition. The LAP data-fusion video was compared to the LWIR and SWIR in the same weather condition (see the curved lines in table 1, page 11).

Procedure

After filling out the sheet with background information the subjects were asked to do a visual acuity and contrast sensitivity test (see previous chapter).
After the vision tests the subjects was brought to another room. Since they had no control of the events in the videos, they were instructed to imagine sitting on the seat next to the driver, looking exclusively at the infrared display and giving notice to the driver when something potentially dangerous could happen. Additionally, they were instructed to always react to soft road users, such as bicyclists and pedestrians, regardless of whether they found the situation potentially dangerous or not. The notice was given by a push on the concept board (touch board). Every push was registered in the 'The Observer-tool' with a timestamp in a text file. Light in the room was dimmed. Before viewing the simulated videos they were shown some videos from the real test drives and practiced using the concept board. After the 6 videos the subject

10 4 = Fusion, fog, night; 5 = long wave, fog, night; 6 = short wave, fog, night; 8 = Fusion, fog, day; 9 = long wave, fog, day; 10 = short wave, fog, day.

was brought back the first room to be interviewed and to answer a questionnaire. They received a gift certificate as compensation. One test was between 1½ - 2 hours long.

Analysis

The scenarios analyzed were the first bicyclist in the middle of the road, the bicyclist and car, the man on the road, and the crossing bicyclist – scenarios 1, 2, 3 and 5. Those scenarios were chosen because most subjects reacted to them in almost all 6 videos. In the figure below the reaction times are registered for all videos and all subjects. In the list on the left the initial letter identifies a subject (e.g. A), the number identifies the video-number corresponding to the numbers used in table 4 (e.g. 4 = fusion, dense fog, night). The rest (FUSnight) is merely added to make the infrared image type and time of day in the video easier to identify in the following analysis. As shown in figure 1, almost all subjects detected and reacted to something about 1.5 minutes in the videos. Also just after 2.0 minutes, after 5.5 and just before 9.5 minutes. The times correspond to the scenarios mentioned the evaluation report.

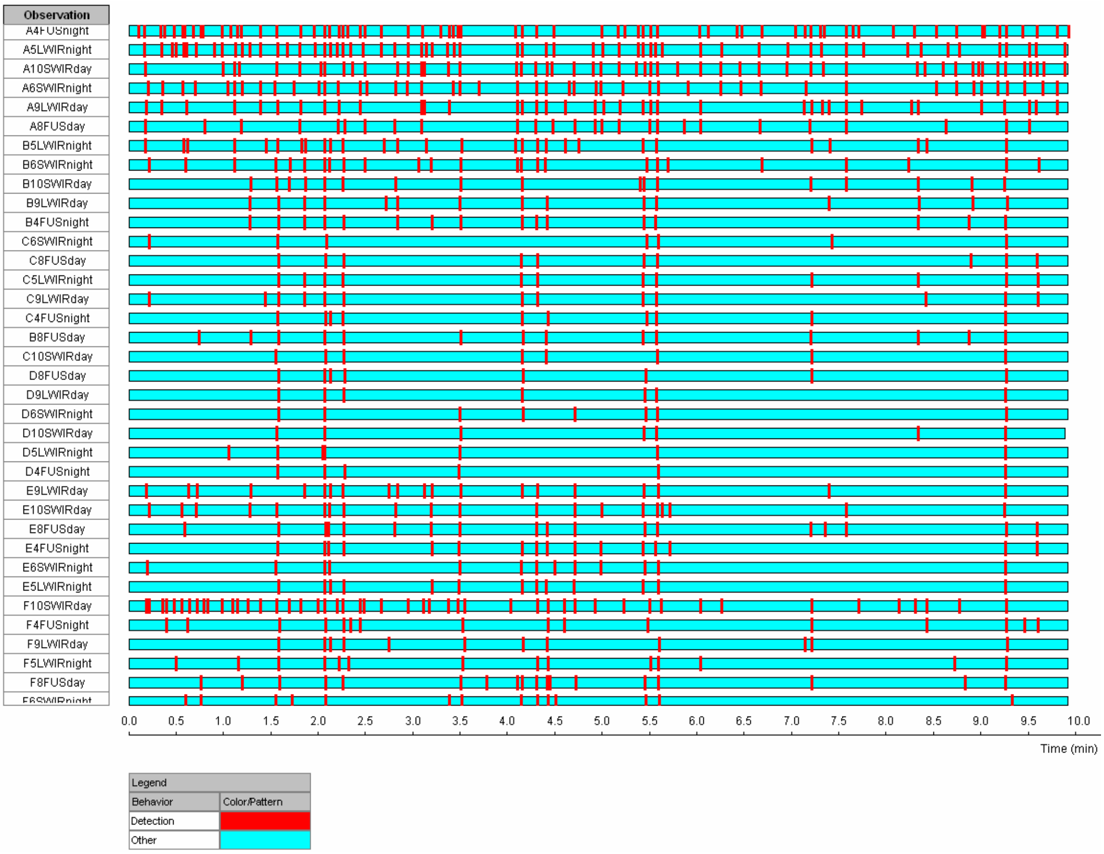


Figure 14: Graphical illustration of reaction times.

We determined a timeframe in which it was possible to see the given scenario in the daylight, clear weather video. E.g. the first bicyclist is visible from approximately 83 to 95 seconds; the bicyclist in the bicyclist/car scenario is visible between 122 - 125 seconds etc. We ran through all the data files with the timestamps to make sure that a given detection fell unambiguously within these timeframes.

Pilot test results

The results were reached by using a two-tailed t-test testing the null hypotheses. The results showed only one significant result in favour of the SWIR daylight, dense fog video in the first scenario with the bicyclist. All other scenarios showed no significant differences in detection times. However there was a tendency toward better detection times (previous detection) for the data-fusion, 8 in favour of fusion, 4 in favour of SWIR, 3 in favour of LWIR, and 1 similar for fusion and LWIR (see annex 6).

Results from vision tests

All subjects had normal visual acuity, 20/25 or better (see annex 4 for more about visual testing). According to the contrast sensitivity no problems were identified.

Lessons learned from interviews, comments during testing and questionnaires.

In the last couple of videos each subject expressed fatigue – either by body language or by speech. In a post-interview, all subjects expressed loss of concentration during the last one or two videos. Some of them recognized elements from the first video already in the second viewing and quickly figured out that it was the same video they were presented with. Fortunately, they did not learn the precise order or location of the scenarios but merely recognized them the moment they saw them. Two of the subjects experienced some motion sickness but not enough to stop the test or take a break.

From the questionnaire we learned that the subjects were not clear about which videos were with the SEE system and which were without. They were even sometimes confused about the different weather conditions. In addition, they expressed a need to be able to distinguish between the fog and the no fog conditions in the questionnaire due to the fact, that some of them were very positive towards the SEE video without fog but had opposite opinions about the SEE videos with fog. It resulted in a revision of the questionnaire to make it possible in the beginning to give their opinions about the clear weather night videos in contrast to the fog videos. Also the procedure of the evaluation was changed, e.g. by introducing a brief viewing and explanation of all of the videos in the end of the session just before filling out the questionnaire and a revision of the experimental design to support the memory of the subjects, as described in the experimental design of the actual evaluation (please, see the Experimental Design section in the evaluation report)

Conclusions from pilot tests

Because there was only one significant result in the analysis in favour of the short wave video whereas the tendency pointed in favour of Fusion, we decided to cut the SWIR and LWIR movies out of the evaluation. The arguments for doing so is first of all that we found no conclusive evidence from the analysis of detection times to support using the LWIR and the SWIR movies, and secondly, that too many videos would tire out the subjects and potentially increase the risks of order- and learning effects.

Statistical data from pilot test

Scenario 1: First cyclist

Day Fus/day SWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	94,528	93,36
Variance	0,05072	0,0672
Observations	5	5
Pearson Correlation	0,08907	
Hypothesized Mean Difference	0	
df	4	
t Stat	7,964953	
P(T<=t) one-tail	0,000673	
t Critical one-tail	2,131846	
P(T<=t) two-tail	0,001346	
t Critical two-tail	2,776451	

Night Fus/Night SWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	93,94	93,11333
Variance	0,37744	0,827787
Observations	6	6
Pearson Correlation	-0,22928	
Hypothesized Mean Difference	0	
df	5	
t Stat	1,674942	
P(T<=t) one-tail	0,077399	
t Critical one-tail	2,015049	
P(T<=t) two-tail	0,154798	
t Critical two-tail	2,570578	

Day Fus/day LWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	94,52	94,52
Variance	0,0672	0,026667
Observations	4	4
Pearson Correlation	0,781127	
Hypothesized Mean Difference	0	
df	3	
t Stat	-4,3E-14	
P(T<=t) one-tail	0,5	
t Critical one-tail	2,353363	
P(T<=t) two-tail	1	
t Critical two-tail	3,182449	

Night Fus/night LWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	93,94	94,26667
Variance	0,37744	0,066987
Observations	6	6
Pearson Correlation	0,603744	
Hypothesized Mean Difference	0	
df	5	
t Stat	-1,59262	
P(T<=t) one-tail	0,086062	
t Critical one-tail	2,015049	
P(T<=t) two-tail	0,172123	
t Critical two-tail	2,570578	

Scenario 2: Cyclist + car

Day Fus/day SWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	124	123,68
Variance	0,1184	0,0664
Observations	5	5
Pearson Correlation	0,360903	
Hypothesized Mean Difference	0	
df	4	
t Stat	2,05874	
P(T<=t) one-tail	0,054304	
t Critical one-tail	2,131846	
P(T<=t) two-tail	0,108608	
t Critical two-tail	2,776451	

Night Fus/night SWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	123,8733	123,9933
Variance	0,103307	0,194187
Observations	6	6
Pearson Correlation	0,480857	
Hypothesized Mean Difference	0	
df	5	
t Stat	-0,73193	
P(T<=t) one-tail	0,248532	
t Critical one-tail	2,015049	
P(T<=t) two-tail	0,497063	
t Critical two-tail	2,570578	

Day Fus/day LWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	124	123,592
Variance	0,1184	0,01232
Observations	5	5
Pearson Correlation	-0,67028	
Hypothesized Mean Difference	0	
df	4	
t Stat	2,138971	
P(T<=t) one-tail	0,049601	
t Critical one-tail	2,131846	
P(T<=t) two-tail	0,099202	
t Critical two-tail	2,776451	

Night Fus/night LWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	123,8733	123,6733
Variance	0,103307	0,028427
Observations	6	6
Pearson Correlation	0,158452	
Hypothesized Mean Difference	0	
df	5	
t Stat	1,447402	
P(T<=t) one-tail	0,103719	
t Critical one-tail	2,015049	
P(T<=t) two-tail	0,207438	
t Critical two-tail	2,570578	

Scenario 3: Man on the road

Day Fus/day SWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	334,32	334,67
Variance	0,071467	0,0068
Observations	4	4
Pearson Correlation	-0,41128	
Hypothesized Mean Difference	0	
df	3	
t Stat	-2,25455	
P(T<=t) one-tail	0,054738	
t Critical one-tail	2,353363	
P(T<=t) two-tail	0,109476	
t Critical two-tail	3,182449	

Night Fus/night SWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	333,92	334,84
Variance	0,5416	0,0896
Observations	5	5
Pearson Correlation	-0,22516	
Hypothesized Mean Difference	0	
df	4	
t Stat	-2,40709	
P(T<=t) one-tail	0,036893	
t Critical one-tail	2,131846	
P(T<=t) two-tail	0,073787	
t Critical two-tail	2,776451	

Day Fus/day LWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	334,48	334,64
Variance	0,1816	0,6856
Observations	5	5
Pearson Correlation	0,855881	
Hypothesized Mean Difference	0	
df	4	
t Stat	-0,69737	
P(T<=t) one-tail	0,26199	
t Critical one-tail	2,131846	
P(T<=t) two-tail	0,52398	
t Critical two-tail	2,776451	

Night Fus/night LWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	333,92	334,04
Variance	0,5416	0,3832
Observations	5	5
Pearson Correlation	-0,07727	
Hypothesized Mean Difference	0	
df	4	
t Stat	-0,26897	
P(T<=t) one-tail	0,400627	
t Critical one-tail	2,131846	
P(T<=t) two-tail	0,801253	
t Critical two-tail	2,776451	

Scenario 5: Cyclist crossing the road

Day Fus/day SWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	555,3267	554,98
Variance	0,052107	0,14384
Observations	6	6
Pearson Correlation	0,290157	
Hypothesized Mean Difference	0	
df	5	
t Stat	2,22458	
P(T<=t) one-tail	0,038343	
t Critical one-tail	2,015049	
P(T<=t) two-tail	0,076686	
t Critical two-tail	2,570578	

Night Fus/night SWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	555,28	556,2467
Variance	0,10048	1,966987
Observations	6	6
Pearson Correlation	0,900465	
Hypothesized Mean Difference	0	
df	5	
t Stat	-2,10375	
P(T<=t) one-tail	0,044664	
t Critical one-tail	2,015049	
P(T<=t) two-tail	0,089327	
t Critical two-tail	2,570578	

Day Fus/day LWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	555,3267	555,2867
Variance	0,052107	0,468747
Observations	6	6
Pearson Correlation	-0,7006	
Hypothesized Mean Difference	0	
df	5	
t Stat	0,113911	
P(T<=t) one-tail	0,45687	
t Critical one-tail	2,015049	
P(T<=t) two-tail	0,913741	
t Critical two-tail	2,570578	

Night Fus/night LWIR t-Test: Paired Two Sample for Means	*Variable 1*	*Variable 2*
Mean	555,28	555,4467
Variance	0,10048	0,058507
Observations	6	6
Pearson Correlation	0,154422	
Hypothesized Mean Difference	0	
df	5	
t Stat	-1,10985	
P(T<=t) one-tail	0,158784	
t Critical one-tail	2,015049	
P(T<=t) two-tail	0,317567	
t Critical two-tail	2,570578	

Annex 7: Results from SEE evaluation

Results from paired t-test

Night no fog **1** **2**

Scenario1 Cyclist

t-Test: Paired Two Sample for Means

	No SEE	SEE
	Variable 1	*Variable 2*
Mean	88,706	88,0625
Variance	7,153899	2,844609
Observations	20	20
Pearson Correlation	0,279002	
Hypothesized Mean Difference	0	
df	19	
t Stat	1,052144	
P(T<=t) one-tail	0,152966	
t Critical one-tail	1,729133	
P(T<=t) two-tail	0,305932	
t Critical two-tail	2,093024	

Scenario2 Car + Cyclist

t-Test: Paired Two Sample for Means

	No SEE	SEE
	Variable 1	*Variable 2*
Mean	125,242	124,654
Variance	2,019954	1,438025
Observations	20	20
Pearson Correlation	0,239719	
Hypothesized Mean Difference	0	
df	19	
t Stat	1,618154	
P(T<=t) one-tail	0,061055	
t Critical one-tail	1,729133	
P(T<=t) two-tail	0,122111	
t Critical two-tail	2,093024	

Scenario3 Man on the road

t-Test: Paired Two Sample for Means

	No SEE	SEE
	Variable 1	*Variable 2*
Mean	298,1326	296,7747
Variance	0,17512	1,553104
Observations	19	19
Pearson Correlation	0,188815	
Hypothesized Mean Difference	0	
df	18	
t Stat	4,783161	
P(T<=t) one-tail	7,44E-05	
t Critical one-tail	1,734064	
P(T<=t) two-tail	0,000149	
t Critical two-tail	2,100922	

Scenario5 Cyclist crossing

t-Test: Paired Two Sample for Means

	No SEE	SEE
	Variable 1	*Variable 2*
Mean	518,252	517,374
Variance	0,517575	0,212594
Observations	20	20
Pearson Correlation	-0,25618	
Hypothesized Mean Difference	0	
df	19	
t Stat	4,138651	
P(T<=t) one-tail	0,000279	
t Critical one-tail	1,729133	
P(T<=t) two-tail	0,000558	
t Critical two-tail	2,093024	

Night fog **3** **4**

Scenario1	Cyclist	
t-Test: Paired Two Sample for Means		
	No SEE	SEE
	Variable 1	*Variable 2*
Mean	92,732	93,454
Variance	0,600775	0,19592
Observations	20	20
Pearson Correlation	0,409885	
Hypothesized Mean Difference	0	
df	19	
t Stat	-4,49738	
P(T<=t) one-tail	0,000123	
t Critical one-tail	1,729133	
P(T<=t) two-tail	0,000247	
t Critical two-tail	2,093024	

Scenario2	Car + Cyclist	
t-Test: Paired Two Sample for Means		
	No SEE	SEE
	Variable 1	*Variable 2*
Mean	126,53	127,848
Variance	1,900105	2,521364
Observations	20	20
Pearson Correlation	0,328101	
Hypothesized Mean Difference	0	
df	19	
t Stat	-3,4115	
P(T<=t) one-tail	0,001464	
t Critical one-tail	1,729133	
P(T<=t) two-tail	0,002927	
t Critical two-tail	2,093024	

Scenario3	Man on the road	
t-Test: Paired Two Sample for Means		
	No SEE	SEE
	Variable 1	*Variable 2*
Mean	297,92	297,6695
Variance	0,107022	0,639083
Observations	19	19
Pearson Correlation	0,218546	
Hypothesized Mean Difference	0	
df	18	
t Stat	1,37386	
P(T<=t) one-tail	0,093177	
t Critical one-tail	1,734064	
P(T<=t) two-tail	0,186354	
t Critical two-tail	2,100922	

Scenario5	Cyclist crossing	
t-Test: Paired Two Sample for Means		
	No SEE	SEE
	Variable 1	*Variable 2*
Mean	518,844	518,494
Variance	0,204278	0,144215
Observations	20	20
Pearson Correlation	0,074232	
Hypothesized Mean Difference	0	
df	19	
t Stat	2,754068	
P(T<=t) one-tail	0,006312	
t Critical one-tail	1,729133	
P(T<=t) two-tail	0,012623	
t Critical two-tail	2,093024	

Day fog

Scenario1	**7** Cyclist	**8**
t-Test: Paired Two Sample for Means		
	No SEE	SEE
	Variable 1	*Variable 2*
Mean	92,742	93,622
Variance	0,205217	2,807827
Observations	20	20
Pearson Correlation	-0,05203	
Hypothesized Mean Difference	0	
df	19	
t Stat	-2,23808	
P(T<=t) one-tail	0,018694	
t Critical one-tail	1,729133	
P(T<=t) two-tail	0,037388	
t Critical two-tail	2,093024	

Scenario2	Car + Cyclist	
t-Test: Paired Two Sample for Means		
	No SEE	SEE
	Variable 1	*Variable 2*
Mean	126,46	127,6556
Variance	0,655482	1,209626
Observations	18	18
Pearson Correlation	0,390711	
Hypothesized Mean Difference	0	
df	17	
t Stat	-4,69076	
P(T<=t) one-tail	0,000105	
t Critical one-tail	1,739607	
P(T<=t) two-tail	0,00021	
t Critical two-tail	2,109816	

Scenario3	Man on the road	
t-Test: Paired Two Sample for Means		
	No SEE	SEE
	Variable 1	*Variable 2*
Mean	297,9511	297,4911
Variance	0,350787	1,00834
Observations	18	18
Pearson Correlation	0,077086	
Hypothesized Mean Difference	0	
df	17	
t Stat	1,733529	
P(T<=t) one-tail	0,050549	
t Critical one-tail	1,739607	
P(T<=t) two-tail	0,101099	
t Critical two-tail	2,109816	

Scenario5	Cyclist crossing	
t-Test: Paired Two Sample for Means		
	No SEE	SEE
	Variable 1	*Variable 2*
Mean	517,772	518,328
Variance	0,151091	0,340817
Observations	20	20
Pearson Correlation	0,338366	
Hypothesized Mean Difference	0	
df	19	
t Stat	-4,27477	
P(T<=t) one-tail	0,000205	
t Critical one-tail	1,729133	
P(T<=t) two-tail	0,000409	
t Critical two-tail	2,093024	

Graphical presentation of reaction times

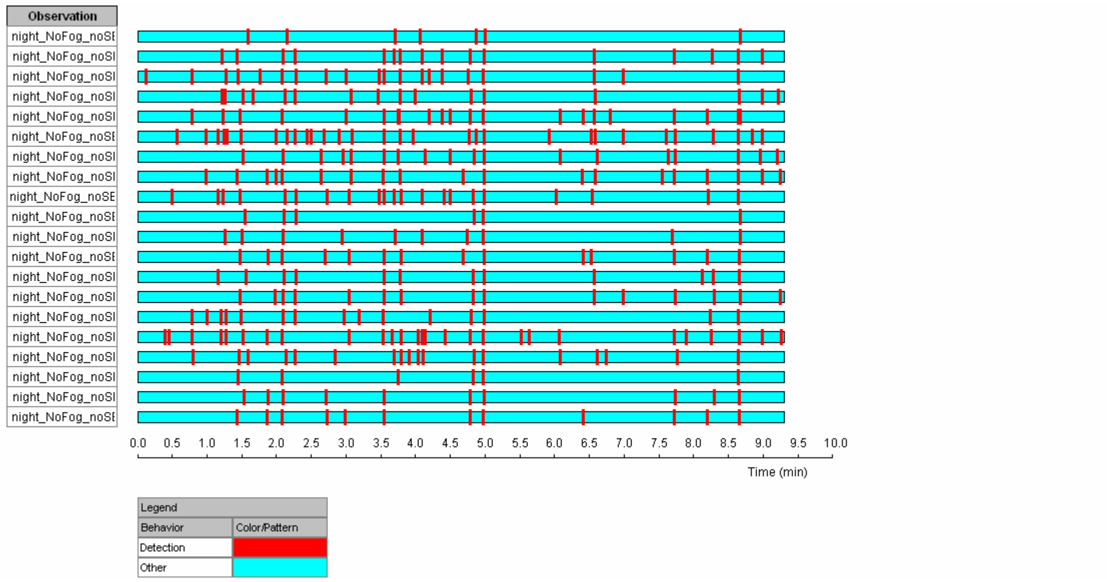


Figure 15: night, clear weather, no SEE

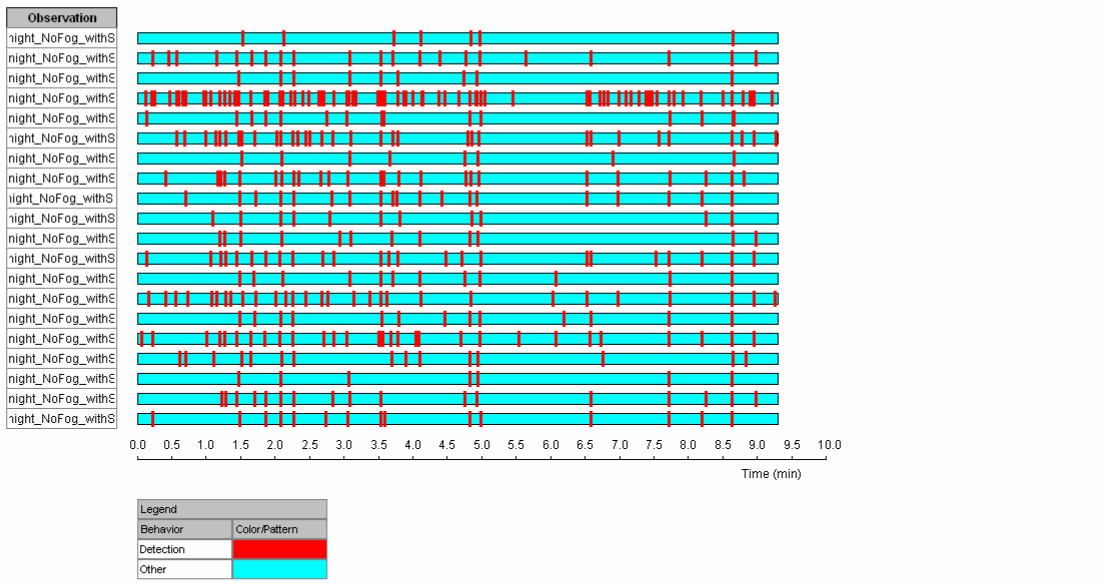


Figure 16: night, clear weather, with SEE

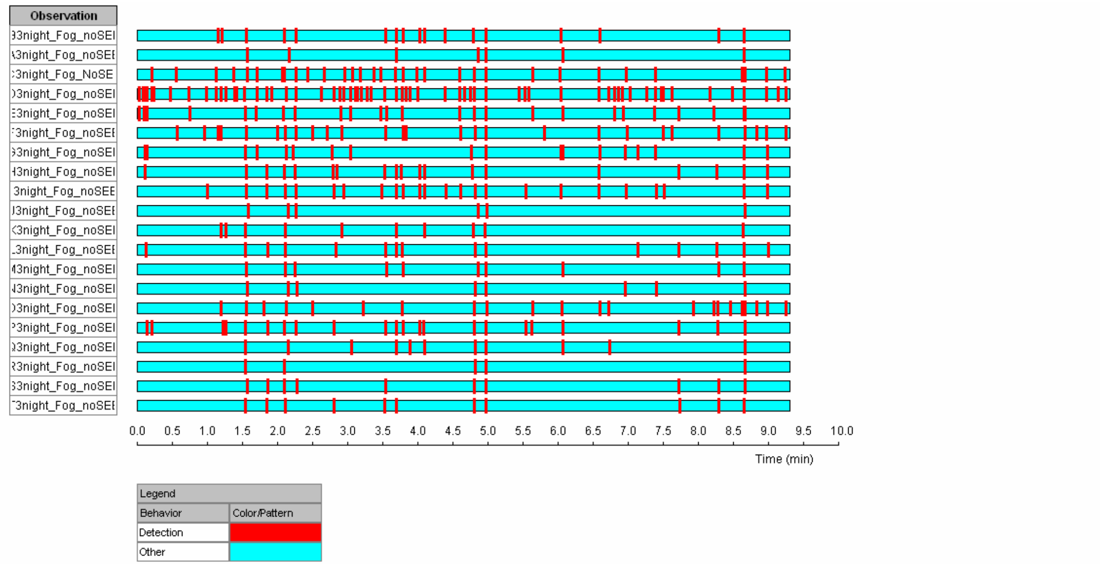


Figure 17: night, fog, no SEE

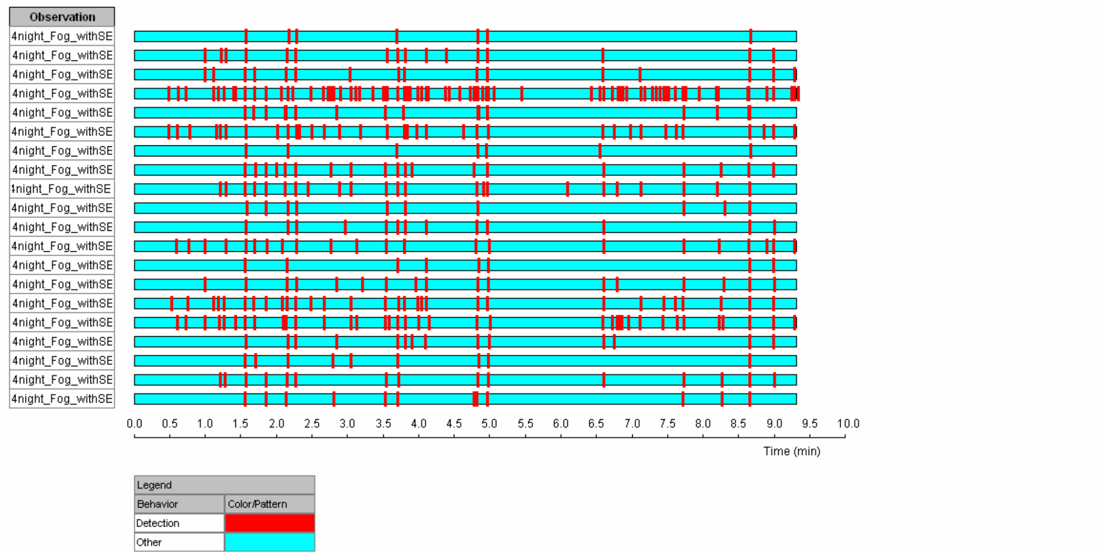


Figure 18: night, fog, with SEE

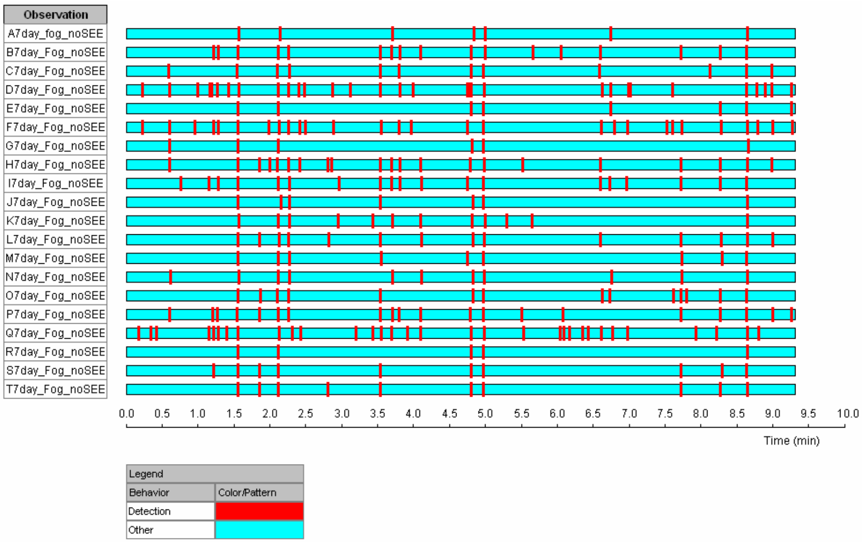


Figure 19: day, fog, no SEE

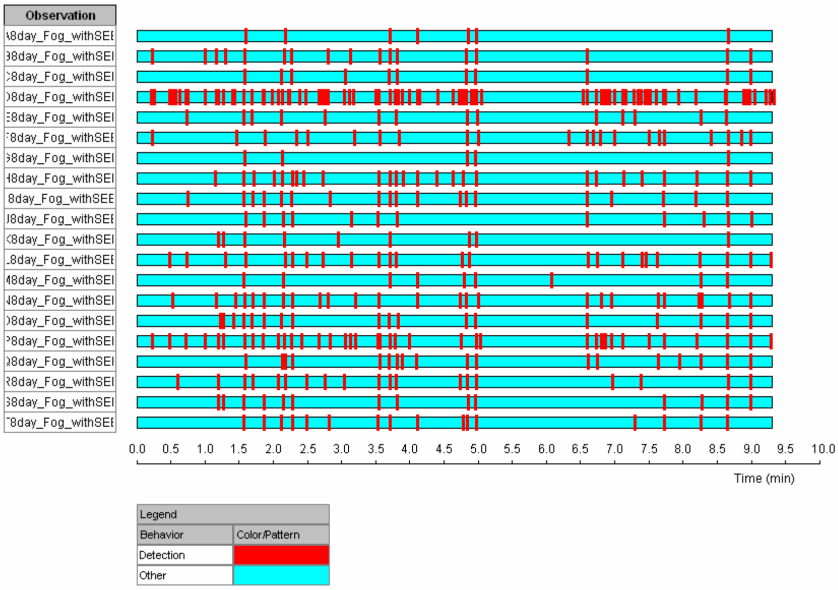


Figure 20: day, fog, with SEE

Examples of detailed indication of time

Start Time	Behaviour
0.00	Other
7.20	Detection
63.00	Detection
71.56	Detection
76.44	Detection
85.68	Detection
99.04	Detection
110.80	Detection
123.64	Detection
134.72	Detection
160.72	Detection
170.36	Detection
211.56	Detection
217.92	Detection
225.88	Detection
268.04	Detection
281.64	Detection
298.32	Detection
390.68	Detection
394.12	Detection
451.28	Detection
462.56	Detection
491.32	Detection
517.48	Detection
536.04	Detection

Table 13: Participant L, night, clear weather, with SEE

Start Time	Behaviour
0.00	Other
88.40	Detection
101.12	Detection
124.56	Detection
134.68	Detection
211.76	Detection
226.64	Detection
266.76	Detection
288.52	Detection
297.36	Detection
371.08	Detection
394.64	Detection
462.60	Detection
517.04	Detection

Table 14: Participant O, night, clear weather, with SEE

Annex 8: Parameterization considerations

The SEE simulations used in the experimental evaluations reported here do not bring out the advantage of the SEE system for visibility in case of foggy weather conditions. This can be explained by the parameterization of the simulations. A great advantage of simulation is that you can set parameters for worst cases (low temperature differences between obstacles and background, types and visibility range of fog).

For example, in the case of the cyclist detection, we have:

- the temperature difference between the cyclist and the background (the fog) is only 3 °C
- the fog is an "advective" fog that is as "opaque" in the LWIR band as in the visible and SWIR band, but we can also take into account a "radiative" fog that is less opaque in LWIR band than in visible and SWIR band
- the visibility range is only 50 m

We have recomputed some images with a different parameterization in order to show that, for other fog condition, the SEE system can work very well:

- a colder fog and background
- a radiative fog instead of advective fog

Parameterization of the initial weather condition

For night + dense fog scenario, the parameterization is:

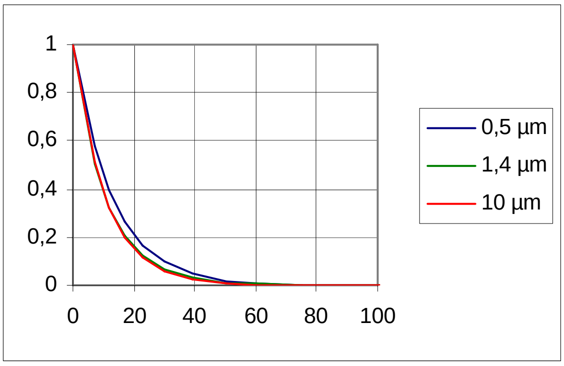
- latitude : 56 N
- longitude : 12 E
- date : 2 Oct 2002 at 3 AM
- air temperature : 13 °C
- haze (aerosol) : advective fog
- visibility range : 50 m

A visibility range of 50 m means that transmission is equal to 0.02 for = 0.55 µm.

Transmission in advective fog

For a horizontal path, the transmission in advective fog according to the distance is:

d (m)	λ = 0,5 µm	λ = 1,4 µm	λ = 10 µm
0	1,0000	1,0000	1,0000
7	0,5798	0,5061	0,5163
12	0,3928	0,3206	0,3221
17	0,2661	0,2052	0,2009
23	0,1668	0,1210	0,1140
30	0,0967	0,0658	0,0589
39	0,0480	0,0303	0,0252
50	0,0204	0,0118	0,0089
60	0,0094	0,0051	0,0035
75	0,0029	0,0014	0,0008
100	0,0004	0,0002	0,0001

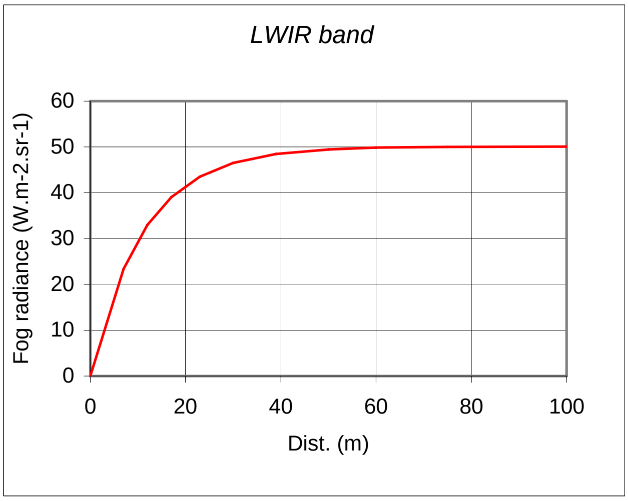


In advective fog, the transmission according to the distance for a horizontal path is nearly the same for the 3 spectral bands (visible, SWIR and LWIR). This point is in agreement with the movies in the visible, SWIR and LWIR: objects appear nearly at the same time whatever the spectral band.

Air temperature versus cyclist temperature

For dense fog simulations, air temperature is equal to: 13°C. This is equivalent to a radiance of 50.3 W.m^{-2}.sr^{-1} in the LWIR band.

d (m)	LWIR
0	0
7	23,430
12	32,941
17	39,032
23	43,545
30	46,534
39	48,467
50	49,473
60	49,841
75	50,038
100	50,106
200	50,116



The cyclist coat temperature is: T_{cycl} = 20°C. As the mean emissivity in the LWIR band is: 0.938, the apparent temperature of the cyclist coat is: 16°C. The difference between the background and the cyclist is only 3°C in the simulations. That is one of the reasons why we have a poor contrast between the cyclist and the fog.

First test: Colder background

We have recomputed the LWIR images for a mean background temperature equal to: 1°C, the same temperatures for the cyclist and the advective fog.

The difference of temperature between the cyclist and the background is 15°C. As a consequence, we have a better contrast in the LWIR band.

Results with a colder background and advective fog

	First simulations	New simulations with colder background
93 s		
93.6 s		
94 s		

In these images (LWIR simulation), the distance between the cyclist and the SEE driver is:

- 36.35 m at date = 93 s
- 28.13 m at date = 93.6 s
- 22.65 m at date = 94 s

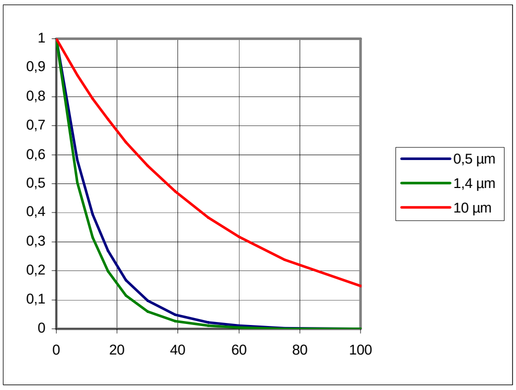
The relative speed between the cyclist and the SEE driver car is 50 km/h.

Second test: Colder background and radiative fog

Transmission in the radiative fog

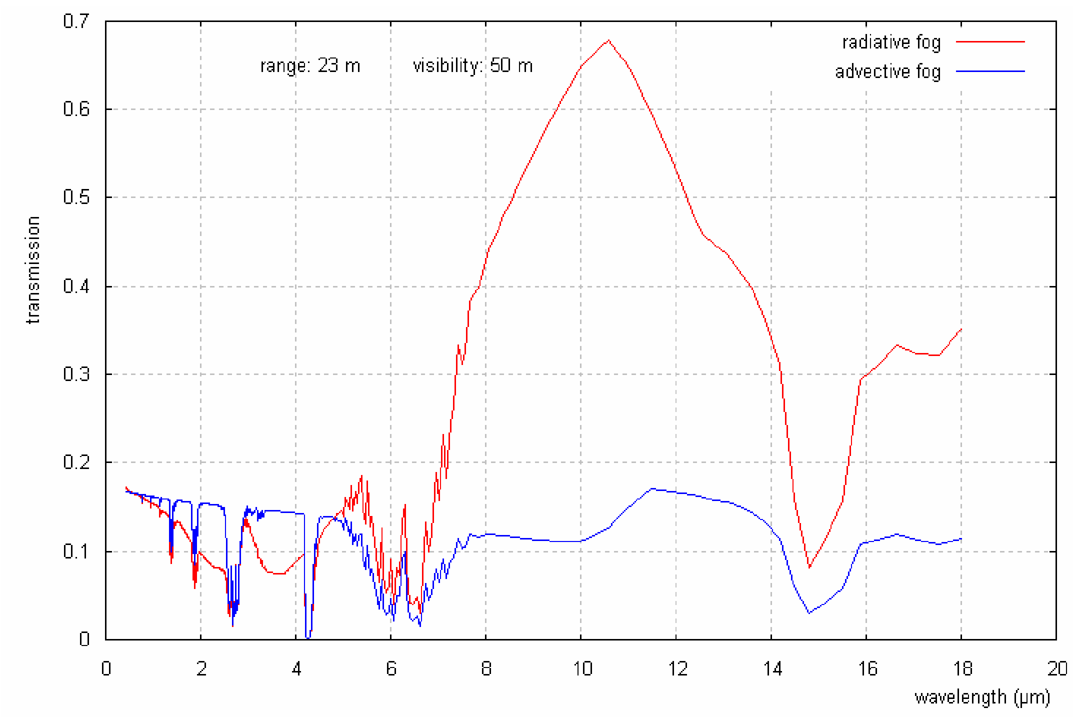
For a horizontal path, the transmission in radiative fog according to the distance is:

d (m)	λ = 0,5 µm	λ = 1,4 µm	λ = 10 µm
0	1,0000	1,0000	1,0000
7	0,581	0,505	0,874
12	0,394	0,315	0,794
17	0,268	0,198	0,722
23	0,168	0,114	0,643
30	0,098	0,06	0,562
39	0,049	0,026	0,473
50	0,021	0,01	0,384
60	0,01	0,004	0,317
75	0,003	0,001	0,238
100	0,0004	0,0002	0,148

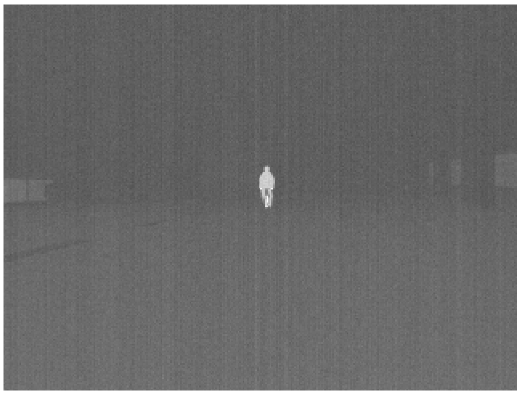
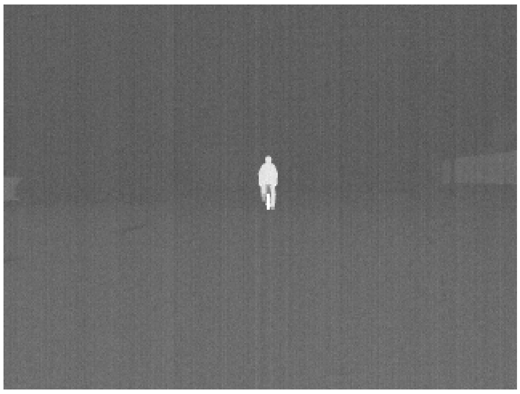
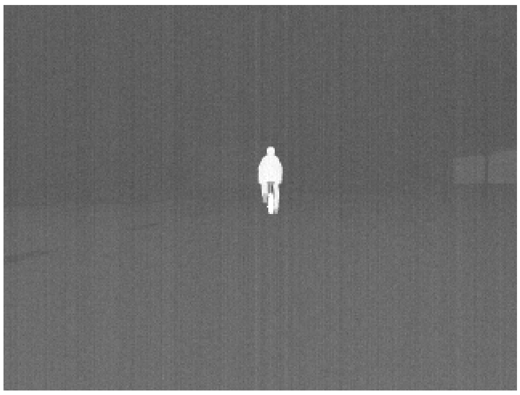


Transmission is LWIR band is better in radiative fog than in advective fog.

The plot below shows the differences of spectral transmission between radiative and advective fog.



Results with a colder background and radiative fog

	First simulations	New simulations with radiative fog and colder background
93 s		
93.6 s		
94 s		

Radiative and advective fog comparison

The table below shows the difference between radiative and advective fog.

Characteristics	Radiative Fog	Advective Fog
	Generally short duration (< 24 hrs), often dissipating by afternoon	Can last for several days
Intensity	Considerable variation is likely especially over open areas or near water sources where fog will tend to be denser. Dense areas may be isolated but can present a hazard to land, air, and sea travel	Can range from thin to dense, but dense conditions may cover larger area than radiation fogs, and changes in intensity tend to be more gradual than with radiation events
Coverage	Typically remains in one place, patchy and localized	May be advected over large areas and across great distances
Depth	Depth will vary with the depth of the radiation inversion. Can be as deep as advection fogs, but tends to be shallower as it is formed by more local factors	Depth can vary considerably with the boundary layer but tends to be deeper than radiation fogs since it is often driven by synoptic-scale factors
Time of Day	Tends to form late at night or in early morning hours. Can also form following precipitation that clears near or after sunset	Can form and advect into a region almost any time of day. Some tendency to develop in late afternoon or evening hours over coastal areas

Dominant processes in advective or radiative fog events

Radiative Fog	Advective Fog
Surface-based cloud caused by nocturnal infrared cooling at and/or near the ground surface	Fog that develops when warm air moves over a colder underlying surface • Surface may be cold ground, snow cover, water, or ice • Cooling of the warm air mass continues until the dew point is reached
Forms and completes its life cycle in situ (although can be advected under the right conditions)	Formed primarily by boundary layer dynamic and adiabatic processes, including advection of moisture, temperature. Dominated by synoptic-scale processes that affect the lifetime of the event. • Radiative processes still play a role in its development and life cycle, but are not dominant
Boundary layer dynamics and adiabatic processes are negligible. Winds generally 5 kt or less. Stronger winds create greater turbulence that can entrain dry air from layers above	Can occur with light or moderate low-level winds (less than 10 kt), but can also occur with winds stronger than 10 kt

Low-level factors

Radiative fog	Advective fog
Moist, low-level conditions below a capping inversion	Differential heating between the underlying surface and the air mass being advected Rapid development can occur when a preconditioned air mass moves over cooler surface. Preconditioning of the atmosphere generally lasts 2-3 days prior to advection fog episodes, especially along coastal areas. (See the *West Coast Fog* module for more information.)
Rapid cooling of the lower boundary layer below the inversion	Air parcel trajectories that originate over a moisture source sufficient to establish a moist boundary layer condition
Presence of a low-level anticyclone, which creates favourable conditions by • Suppressing surface winds • Drying the air aloft through subsidence, enhancing radiative cooling at the surface • Providing a capping inversion	Depth of the surface-based moist layer increases as a result of mechanical turbulence and convective mixing of buoyant moist air, which can give a thicker fog layer. Large-scale anticyclonic winds and subsidence provides capping inversion so boundary layer can saturate.
Moderate vertical shear often exists near the capping inversion.	Moderate vertical shear often exists near the capping inversion.

Risø's research is aimed at solving concrete problems in the society.

Research targets are set through continuous dialogue with business, the political system and researchers.

The effects of our research are sustainable energy supply and new technology for the health sector.